MODERN AIRCRAFT

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BASIC PRINCIPLES OPERATION APPLICATION
CONSTRUCTION REPAIR MAINTENANCE

A COMPLETE, PRACTICAL TREATISE OUTLINING CLEARLY THE ELEMENTS OF AERONAUTICAL ENGINEERING WITH SPECIAL REFERENCE TO SIMPLIFIED EXPLANATIONS OF THE THEORY OF FLIGHT, AERODYNAMICS AND BASIC PRINCIPLES UNDERLYING THE ACTION OF BALLOONS AND AIRPLANES OF ALL TYPES. A BOOK FOR ALL STUDENTS OF AIRCRAFT

This book includes instructions for lining up and inspecting typical airplanes before flight and also gives easily understood rules for flying and aircraft power plant design, installation and care

BY

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Contains valuable instructions for all aviation students, airplane mechanicians, flying field engineering officers and everyone interested in construction and up-keep of airplanes

A SIMPLIFIED TEXT SUITABLE FOR SCHOOL OR HOME STUDY

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PREFACE

As a result of wide and valuable experience obtained while an aeronautical engineer officer in the United States Army Air Service in active service both in this country and abroad, part of which time was spent in instructing prospective aviators and mechanics, and in response to an insistent demand, the writer prepared a treatise on airplane power plants called "Aviation Engines," which met with a very gratifying reception and which was used by many aviation schools as a text on this subject. Instructors who had been using the engine book successfully and numerous students who had derived some benefit from its contents have asked for an exposition of the airplane in which its operation and repair principles would be explained in the same simple non-technical manner as the treatise referring to power plants.

To meet this demand, the present treatise has been prepared and instructors, both civilian and army officers, who have read the manuscript have pronounced the book as one well suited for instruction work. It is not intended to be an engineering treatise, or is it intended to consider technical points that can interest only the designer. At the same time, it is necessary to consider some of the basic principles of airplane flight and aerofoil design in simple language so the student may obtain a complete grasp of the elements of the subject. For those seeking technical knowledge, numerous excellent reference works and Government publications are available. Books for boys are also on the market, defining the subject in very simple language so neither of these extremes has been considered in preparing this text, because any need for the above can be met with existing works.

The notes on inspection and lining up of airplanes have been purposely made brief and may apply to airplanes in general, as well as the specific types illustrated. This also applies to the instructions, or rather observations, on flying which have been suggested by a pilot of considerable experience as flying cannot be learned by the ordinary person by reading and even experts require constant practice in the air to maintain their skill. Every effort has been made to explain the most important of the many technical points and numerous diagrams have been prepared to amplify the text. It is believed that this treatise, owing to its having been prepared with a full realization of the average student's needs, should be well adapted for instruction work on general principles of mechanical flight and their practical application in both lighter-than-air craft and airplanes. The book should be as well adapted to general reading and for reference and to home study work as it is for classroom instructions.

New types of engines in both air- and water-cooled types that have commercial possibilities are described and illustrated and complete directions are given for their installation and care. Various models of recently designed airplanes and seaplanes and their principal characteristics are described. There has been so much done in aeronautics that it is impossible to describe all types of engines or airplanes in a treatise of this scope, so the types selected are those

that may be considered typical of either early design or more modern developments. There are many good engines and airplanes that could not be described because of lack of space.

The recent performances of both types of aircraft; including the large airships and smaller airplanes have created a great and active interest in aviation and aerostation on the part of the public and much thought and study is being given to the commercial applications of aircraft. For this reason, rather extended consideration is given to some of the aspects of commercial aviation and notes are included in this new edition on aerial navigation and night flying so some of the practical problems facing those wishing to develop aviation can be realized.

VICTOR W. PAGÉ.

ACKNOWLEDGMENT

The science of aeronautics is now composed of so many distinct branches that a proper appreciation of the many phases of any one of these can only be obtained by individuals specializing in it. In preparing this treatise the author has made frequent references to the authority responsible for the opinions or information presented and in every case, due acknowledgment is made in the text to the expert quoted. There are many sources of aeronautical data at the present time besides the manufacturers of airplanes and engines and auxiliary apparatus. Government documents and publications of the Engineering Division, U. S. Army Air Corps with headquarters at McCook Field, Dayton, Ohio, and also those of the National Advisory Committee of Aeronautics, Washington, D. C., have been consulted freely and excerps and abstracts from these public documents have been used to bring out points in the text that were considered in great detail in reports of experts and specialists. The United States Bureau of Standards, Washington, D. C., has also published much valuable data in the form of reports issued in co-operation with the Government agencies previously mentioned. The membership of the Society of Automotive Engineers, Inc., includes many aeronautical experts and specialists, and much valuable data has been published in the S. A. E. Journal on aviation and kindred subjects. The publication "Aviation" of New York City, a weekly magazine, was also of great value and references to its editorial opinions and descriptions of aircraft have also been included to justify and support some of the opinions of the author. Such leaders in the industry as the Goodyear Tire and Rubber Co., Akron, Ohio, the Curtiss Aeroplane and Motor Company, Inc., of Garden City, New York, Packard Motor Car Co., Detroit, Mich., and the Wright Aeronautical Corporation, Paterson, New Jersey, as well as numerous other firms whose products are described in the text furnished valuable illustrative and descriptive data. The Bureau of Aeronautics, U. S. Navy and the Information Section, U. S. Army Air Corps also furnished material pertinent to Service planes, airships and engines.

The writer desires to acknowledge the valuable assistance obtained from the sources mentioned as they have greatly supplemented the material in the original instruction papers for students and the author's experience in aviation since its inceptions over a two decades ago, that forms the groundwork for this treatise.

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MODERN AIRCRAFT

CHAPTER I

AIRCRAFT TYPES

Distance no Longer Computed in Miles—Brief History of Early Flights—First Channel Crossing—Force of Air in Motion—Structure of the Atmosphere—The Stratosphere—The Troposphere—Ascensional Power of Warm Air—Lifting Power of Hydrogen Gas—Types of Dirigible Balloons—Heavier-than-Air Machines—Why Airplane is Best—Attraction of Gravity—Kite Supported by Air in Motion—Air Resistance—Resistance of Aerofoil Sections—How Air Pressure Varies with Speed—How Airplanes Differ—Monoplane Development—Flying not Inherently Dangerous—Good Pilots Essential—Possibilities of Aviation—Aviation and Insurance—Standard Definitions.

The navigation of the air, which has been the dream of mankind for ages, has only been realized in recent years. Practical aircraft have been built in definite forms that can easily be classified, and also in several experimental types that are little known and which have been discarded in favor of the types known to be practical. The air is a gas composed of oxygen and nitrogen that surrounds the earth and which is said to extend above the earth's surface for about 40 miles, though the density becomes less and the air becomes rarer as the distance above the earth's surface increases. Above a certain height, about four or five miles from sea level, it is very difficult for human beings to breathe because of the rarity of the air. We are so used to moving about in the air that many consider it an almost intangible substance and do not realize that 16 cubic feet of air will weigh about a pound and that it exerts a pressure of about 15 pounds per square inch surface on everything at sea level. We are so constituted that this load is not appreciable to us any more than the force of gravity. Everyone knows, of course, that if there were no air there could be no life, but probably very few fully realize its immense importance in almost everything we do. In one condition it is invigorating and gives us a zest for hard work whether mental or physical; in another it leaves us depressed and incapacitated for efficient labor. Numerous manufacturing processes are radically affected by the amount of moisture in the air and many others by its temperature. Power is transmitted by it; we communicate our thoughts to one another by vibrations of the air, and by its aid we have recently acquired our swiftest mode of travel. In the last few years, several elements, helium, argon, neon, krypton and xenon, have been found in the atmosphere that previously were unknown and even unsuspected. One of these, argon, amounts to nearly 1 part in 100 of the whole atmosphere, and yet through decade after decade of chemical investigations involving countless thousands of air analyses, it, and all its family of gases, remained undiscovered.

Distances No Longer Computed in Miles.—Distance today is no longer computed in miles, but in the expenditure of time required to travel from

one place to another. Aircraft in the past decade has played an important role in bringing to pass this new aspect and conception of distance. Cities, towns, communities, and even countries, once remote from other centers, have, through quickened travel by air, come into closer contact and more complete communication, for distances may now be translated into minutes instead of hours, and into hours instead of days. The airship "Los Angeles" has been driven without stop across the Atlantic Ocean from Central Europe to the United States in 80 hours and from land's end to land's end in 61 hours. Even the fastest liners, conceived by builders with the experience of centuries behind them, require five days or more to transverse lesser distances from American ports to those of Europe. A relatively small Ryan monoplane, powered with one Wright 220 H.P. Whirlwind motor and piloted by Captain Charles Lindbergh, made the trip from New York to Paris, a distance of 3,800 miles in 33 hours and 30 minutes on

The airships Z12 and L30, built by the old Zeppelin organization, successfully rode through repeated violent line squalls for an entire night, were during that time repeatedly struck by lightning, and came back to their home bases uninjured. The Zeppelin "Dixmude" stayed aloft 118 hours, or nearly five days, to establish a world's duration record for aircraft. The British-built R-34, constructed in the earlier days of the art in Great Britain, crossed the North Atlantic to this country and returned without mishap. The comparatively small semi-rigid Italian ship, "Norge," chartered by the Amundsen polar expedition, and piloted by General Umberto Nobile, flew from Spitzbergen to the North Pole in 1926 and on across the top of the world to a point near Nome, Alaska. The accomplishment of Commander Byrd, and his pilot, Bennett, of flying from King's Bay, Spitzbergen to the North Pole and return with a three engine Fokker monoplane prior to the flight of the Norge was also an achievement worthy of record in aeronautic annals. Six American army fliers in American built Douglass biplanes have circled the globe on wings, flying over cities, mountains, glaciers, jungles, deserts, and oceans, returning again in safety, and another group, in Loening Amphibian biplanes have just returned from a trip to South American countries during which thousands of miles were covered by air.

The army transport airplane "T-2," piloted by Lieutenants J. A. Macready and Oakley G. Kelly, of the U. S. Air Service, passed across the continent in 35 hours without stop, establishing a new American duration record for airplanes, which stood until Bert Acosta and Clarence Chamberlin kept a Wright Bellanca monoplane aloft for over 51 hours during the early part of This also was equipped with a Wright motor.

A tiny airplane, piloted by Lieutenant Russell L. Maughan of the U. S. Army, bullet-like has made its way from New York on the east to San Francisco on the west between the brief hours of dawn and darkness, and United States air mail planes regularly span that distance in what approximates two days. This splendid service, operating day and night in what often seem to be impossible weather conditions, has been one of America's finest contributions to the science of flying and to the practicability of commercial air transport. The best transcontinental trains, running on

schedule, require two days longer in the transfer of mails across the United States.

Man has ascended in airplanes to altitudes of nearly seven miles above the earth's surface.

Brief History of Early Flights.—Since the start of recorded time man has envied the bird in its flight across the sky above him. Man watched smoke ascend from his fires into the clouds and travel on the winds, later visioning in smoke a potential lifting force that challenged imagination and human ingenuity. Even the early philosophers and scientists dreamed of man flight and drawings have been handed down from remote antiquity that show arrangements of flapping wings to be operated by the arms and legs of the aviator. Among the drawings of Leonardo DiVinci, the medieval artist, engineer and soldier; several sketches of flying machines were found, one of which resembled the airplane in form, several incorporating wing flapping mechanism doubtless copied from birds, but history does not record that any of these devices were ever constructed or even tried.

In the early years of the eighteenth century experimenters who stalked the first principles of aeronautics were increasingly numerous, though even before that period all manner of daring mechanical devices and flying gear had been constructed in the hope of finding a means of locomotion for man through the air. It remained for the Montgolfier brothers to complete the first practical balloon design in June, 1783. Their 35-foot paper bag inflated with hot air and smoke from burning damp straw, sailed away from the little French village of Annonay.

The Academy of Science in Paris, on learning of the unusual event, summoned the Montgolfiers to repeat the demonstration in the capital. While the brothers were fashioning their second balloon, a Paris physician named Charles, assisted by the Roberts brothers, instrument makers, constructed a silk balloon of approximately 1,400 cubic feet capacity, and sent it aloft inflated with hydrogen gas in August, 1783. A month later, when the elder Montgolfier arrived in Paris and learned of the ascension of the Charles balloon, he decided to surpass his competitors by placing a sheep, a rooster and a duck as passengers aboard his balloon. This flight from the courtyard at Versailles was successful, the unusual cargo landing safely. Then a young gallant of that day named De Rozier decided to be the first man in the world to make a balloon flight, and in spite of the opposition of King Louis XVI, he sailed over Paris in November, 1783, in a balloon of Montgolfier construction while hundreds of Parisians applauded.

First Channel Crossing By Balloon.—Benjamin Franklin was one of the witnesses of these earliest flights. Two years later, Blanchard, a Frenchman, and Dr. Jeffries, an American practicing in England, made the first balloon flight over the English Channel, leaving Dover at one o'clock in the afternoon and landing safely in Calais three hours later.

Balloons were used for military observation purposes during the French Revolution and in the American Civil War, and the Franco-Prussian War, and were utilized on a large scale in the World War. The essentials of free ballooning, including the gas-tight bag, the gas valve, the net and the basket which carried the pilots, were all developed in the 18th century.

However, these balloons rode with the wind, had no power to direct

their course. So men began to experiment with power-driven gas bags. In 1852 Henri Giffard, a French inventor, built the first power-driven balloon, a dirigible 145 feet in length deriving its motive power from a three-horsepower steam engine. Under favorable conditions this airship had a maximum speed of five miles an hour.

Though the modern, long-range airship, of which the Montgolfier balloon and the Giffard airship were progenitors, was to wait for the gasoline engine and the marvelous light metal, duralumin, many experimental airships were built toward the end of the 19th century, the greatest success being achieved by Santos Dumont, a Brazilian residing in Paris, who built 14 airships in six years, each more efficient than its predecessor, and with the last won a 100,000 franc prize for flying around the Eiffel Tower.

At about the same time an Austrian named Schwartz built the first all-metal airship, using a framework and outer covering of aluminum. His ship, however, was destroyed on its first landing. In the meantime Count Ferdinand Zeppelin evolved the idea of the rigid airship which bears his name while a soldier in the Union army during the American Civil War, and in 1900 in Germany completed and flew his first craft.

France, Italy and England began building airships of the non-rigid and semi-rigid type. America's first airship, a non-rigid type of 20,000 cubic feet capacity, was built in 1908 by the late Major Thomas S. Baldwin and was provided with a Curtiss motorcycle engine for power for the Army Signal Corps and used for training purposes. This same outfit, modified in several important particulars, fitted with control elevator and variable pitch propeller was experimented with by Stuart Bastow and the writer in 1909-10 at Pawtucket, Rhode Island and a number of successful flights were made with the improved apparatus. In 1916 the United States Navy began to use small airships for coast patrol, submarine spotting during the World War, and for training flying personnel.

The modern airplane began to receive serious consideration only after numerous gliders had been built by Liliendahl in Germany and Octave Chanute, a Chicago architect, in this country. The early work of Dr. Samuel Langley and Charles Manly of the Smithsonian Institute, Washington, D. C., early in the twentieth century was the pioneer work on self-propelled heavier-than-air craft.

Force of Air in Motion.—Air in motion may exert considerable force. A gentle breeze creates very slight pressure, but a cyclone or hurricane, which means air travelling at a rate of from 75 to 100 miles per hour, can do considerable damage. Much destruction is caused by tornadoes due to the great pressure of air travelling at a high speed, and which has sufficient velocity to uproot large trees and tear buildings apart. Winds are caused by the conflict between rising air currents due to the lesser weight of heated air which rises from the earth's surface and the down currents of cold and therefore heavier air which rushes down to take its place. The physical contour of the earth and variations of temperature as well as seasons of the year all have their influence on air movements termed winds. For example, the hot summer sun beating down on a sandy plain will saturate the earth with warmth and ascending air currents will move at greater velocity than will air currents ascending from a forest. An aircraft, passing

from the hot, rapidly ascending air current to the slower moving, cooler air from the forest will lose lift and may drop appreciably in the cooler air column.

Structure of the Atmosphere.—The Director of the Blue Hill Observatory, Harvard University; Alexander McAdie, who is an authority on the structure of the air gives some interesting facts about the atmosphere. He says:—

"Air is a mechanical mixture, not a chemical compound. Four-fifths of the air is Nitrogen and other fifth mostly Oxygen. But there are two additional quantities, independent variables, water vapor and dust, both important as affecting aviation. In fact, it is water vapor that is responsible for most of a flyer's troubles. Fog, poor visibility, snowstorms, thunderstorms, are all manifestations of change of form of water. If there be extreme dryness, parts of the machine are warped; if too damp, there are bad effects. The plane or airship may get an ice coating and the load be so great that there is a forced landing.

"Contrary to expectation and to some degree contradicting fundamental equations in physics, the atmosphere is not homogenous. Pressure, temperature and even density do not decrease as we go up, at a fixed and uniform rate. We cannot regard the atmosphere as a single layer. Tidal equations cannot be applied. The atmosphere is actually a series of airspheres; and these are not exactly concentric shells. Not only do we find stratification or layers; but even striation."

The Stratosphere.—We know two distinct shells—the lower or troposphere, a region of turning, also of convection about ten kilometers or six miles thick in our latitudes. This is the layer in which weather occurs. An upper shell is the stratosphere, or so-called isothermal region in which temperature does not continue to fall with increase in altitude. Half a dozen fliers have half reached the stratosphere or have gone a slight distance into it.

Macready of the U. S. Air Corps reached the height of 11,454 meters or 37,569 feet in March, and Calizzo, a European flier holds the present height record of 12,066 meters or 39,576 feet, approximately.

Both of these pilots have gone beyond the limit of cloud formation. In others words, they passed through and beyond the region in which weather occurs. It is bitterly cold up there but there are no changes.

The Troposphere.—The lower airsphere, the troposphere, bulges up at the equator and contracts at the poles. If Commander Byrd could have stopped long enough when he was at the North Pole to make an altitude record, he would have passed through the troposphere at 4,000 meters and into the stratosphere. On the other hand, at the equator he would have to go up 17,000 meters to get into the isothermal layer.

A pilot can get pressure and temperature by direct reading but there is no instrument to tell him the density of the air. It happens that at 8,000 meters the density is practically constant over all the globe. Above this height, air is denser over the equator than over the poles. In fact, density appears to be a function of pressure and temperature in low levels but not in high levels. Hence two words have been introduced into the language—barosphere and thermosphere—one to represent the region where pressure

controls, and the other for the region where density is a function of temperature.

Ascensional Power of Warm Air.—The ascensional power of warm air was well known to the ancients, and the first craft to navigate, or rather be supported in the air, were very large globular or pear-shaped bags of paper or parchment filled with hot air and smoke from a fire burning beneath the opening in the bottom of the bag. A cork or piece of wood floats on water because it is lighter than the supporting medium, a stone sinks because it is heavier than water. A bag filled with hot air, smoke and gases, resulting from combustion, is lighter than the surrounding cold air it displaces and will rise because it is of lesser weight than an equal volume

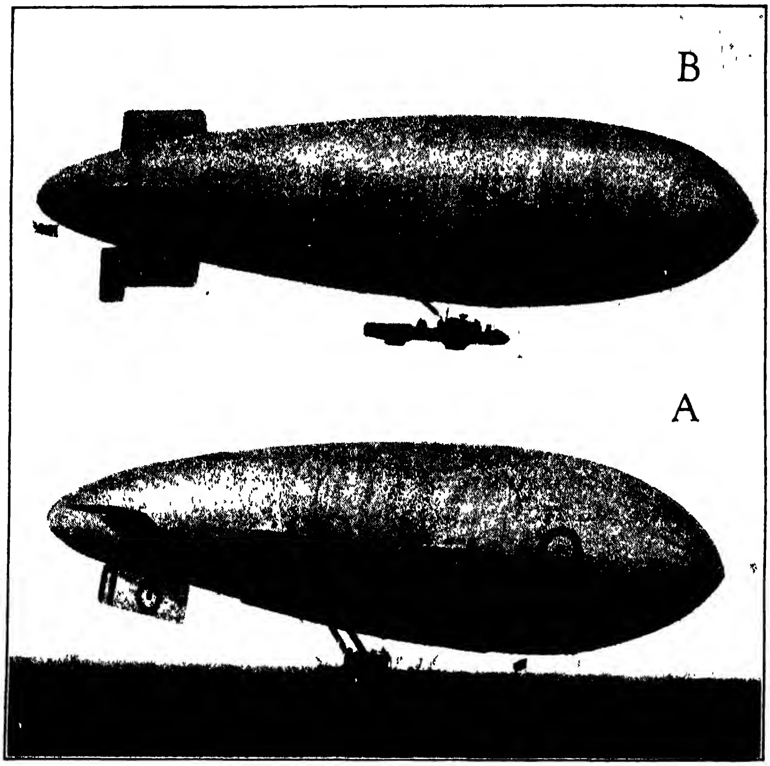


Fig. 1.—Typical Non-Rigid Types of Dirigible Balloons. A—U. S. Army T 11 Being Landed by a Ground Crew. B—U. S. Army T 5 in Flight.

of the supporting medium. Its action is not comparable to an object floating on the surface of the water, however, with only a portion of its area submerged but rather like that of an object floating submerged and entirely supported by the surrounding fluid. The first airships were of the lighter-than-air type and were called balloons. This type is made in three forms, aerostats or spherical balloons free to rise in the air and blown hither and yon at will of the elements, anchored gas bags of special form known as "kite" balloons, and dirigible balloons, which are driven by power and which may be steered by special directional mem-

bers or rudders. The free balloon is of little value except for exhibition and instruction purposes. The kite balloon, however, which is held captive is a splendid type for military observation purposes.

Lifting Power of Hydrogen Gas.—Practical balloons are made up of various textile fabrics, such as silk or linen, which are very closely woven and which are impregnated with rubber compound to lessen the porosity in order that they may retain gas. This cloth is cut into strips of the proper size and shape which are sewed together to form the envelope or gas bag. The seams are covered with strips of rubberized tape to insure a gas-retaining joint. The bag is usually filled with hydrogen gas, the lightest known element. One cubic foot of this gas is capable of lifting one ounce weight, therefore a bag with a capacity of 32,000 cubic feet would be able to lift one ton or 2,000 pounds, this weight including the gas, bag and basket and objects raised from the ground. Some free balloons are inflated

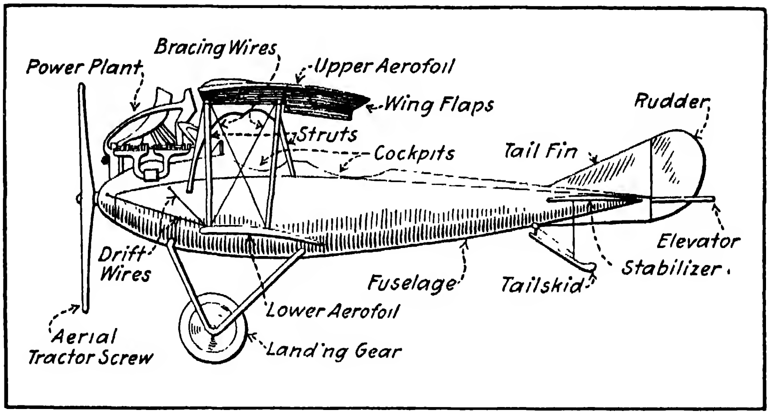


Fig. 2.—Side View of Typical Biplane, Showing Important Parts.

with coal gas, which is cheaper than hydrogen and dirigible airships used by the government use helium gas, which has about nine-tenths of the lifting power of hydrogen and which has the big advantage of being non-inflammable. A more extended description of this gas will be given in proper sequence. The kite balloons are shaped like a big sausage instead of a pear or globe and are allowed to rise to the desired height by unwinding a cable from a power-driven winch.

Types of Dirigibles.—Dirigibles are made in three types called non-rigid, semi-rigid, and rigid. The former class includes a streamlined-shaped bag carrying a basket or body member suspended from the bag by a series of slings, these being attached either to a netting or to special fabric anchorage pieces sewed to the bag. The bag holds its shape because it is distended by the internal gas pressure. The semi-rigid type has a triangular keel member along the underside of the gas bag to which the power cars and control cabin are attached. The rigid type, of which the well-known Zeppelin airship is an example, has a metallic framework that divides the main gas container into sections, the only function of the gas bags being to hold the gas. The framework shapes the bag and permits

of easy attachment of the "gondolas" or cars carrying the power plants close to the body of the ship. A good example of a rigid dirigible is the "Los Angeles" shown at top of Fig. 3. The semi-rigid "Norge" is shown below the "Los Angeles" and is the airship in which General Nobile, its designer and Messrs. Amundsen and Ellsworth flew over the North Pole. The non-rigid Goodyear "Pony Blimp" is a good example of that form of construction. The non-rigid is limited in size because of structural considerations as is the semi-rigid, but the latter can be made much larger than the former. The rigid type is the only practical one for large capacity dirigibles. These types will be considered more in detail in proper sequence.

Heavier-Than-Air Machines.—Heavier-than-air machines may be divided into three types: airplanes, helicopters and ornithopters. The first named is made in three different patterns designated by the number of supporting surfaces or wings it has. A monoplane has one wing; a biplane, two; and a triplane, three. The helicopter is a machine that depends on lifting screws for sustentation and propellers for securing movement in a horizontal plane. The ornithopter is a type devised to imitate bird flight and sustentation is supposed to be derived by the flapping of wings. Neither of the two latter forms is practical or seems to have any future.

The airplane in its simplest or monoplane form consists of a body to carry the pilot, power plant and controlling members, supported by wings, one at each side of the body. The engine turns an aerial propeller which pulls the machine through the air because the air pressure under the wing and the suction effect on top of the wing exerts a lift greater than the weight of the machine if it is drawn through the air with sufficient speed. The airplane in its various forms will also be discussed in succeeding Chapters. The airplane is the most practical type of machine to navigate the air and thousands are in daily use. Its principle of operation is easily understood. If wind moving at high velocity exerts pressure, drawing an object through the air at high speed will produce pressure against it. If this is a plane section, such as a kite, it will rise because of the wind beneath it. Airplane wings may be compared roughly to a kite, the propeller thrust or tractor screw pull can be likened to the tension of the kite string when one runs along the ground to raise the kite. Modern airplane wings, however, have such form that their efficiency is much higher than that of plane surfaces because the camber gives better aerodynamic properties and greater lift for a given area.

Why the Airplane Is Used in Large Numbers.—One can hardly conceive of a man even of enormous wealth, who would maintain an ocean liner for personal gratification or as a means of obtaining pleasure. It is evident that amusement and recreation could be secured at much less expense by the use of smaller and no less practical craft. This is really the condition that obtains in the field of aeronautics, and before the problem of aerial navigation can be said to have been solved it will be necessary to produce practical creations which will be light, speedy and mechanically reliable. One must look to the heavier-than-air class to find flying machines which give promise of becoming sufficiently practical so as to be within the reach of the average individual prospective user. The prin-

ciples underlying the construction of lighter-than-air craft are such that extremely large sized balloons must be built, because the small lifting power obtained by the use of the gases lighter than air is wholly disproportionate to the large dimensions of the gas container, and their use will be limited to government military and naval services and to trans-oceanic

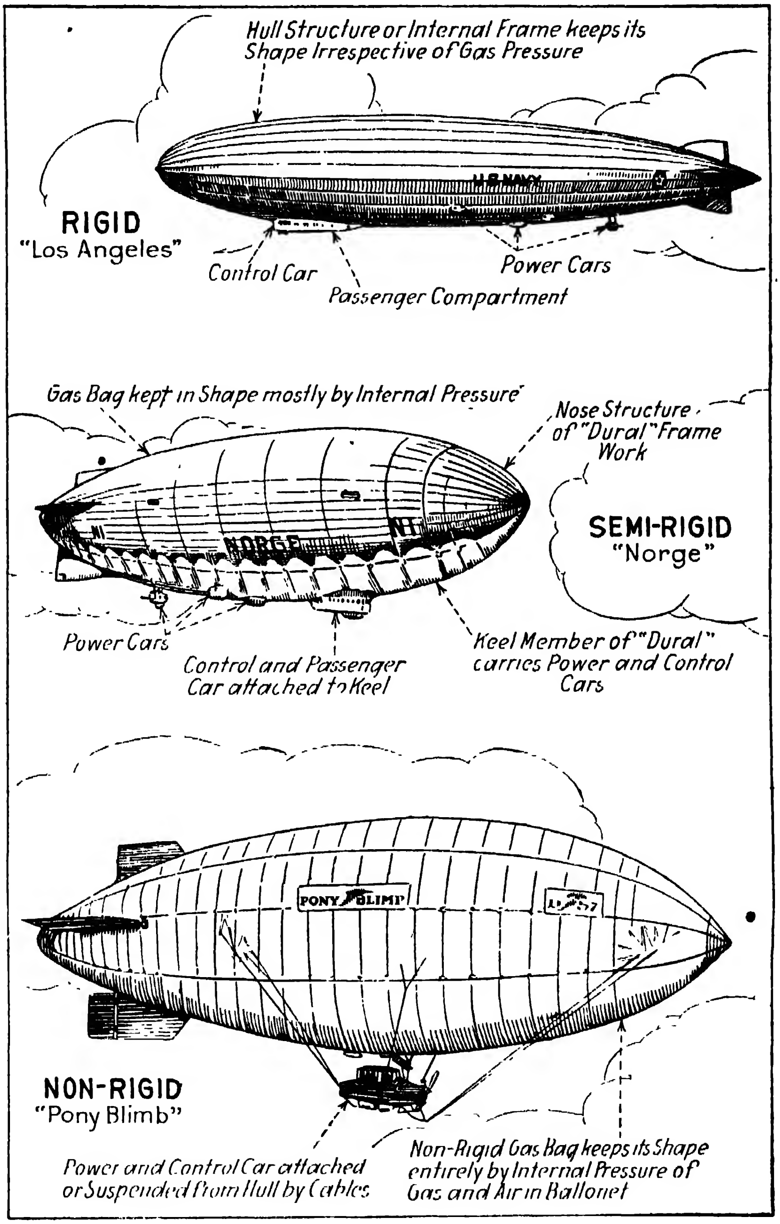


Fig. 3.—Illustrations Showing the Three Main Types of Dirigibles. At the Top—The Rigid Type "Los Angeles" a Navy Zeppelin of Very Large Size. In the Center—The Semi-Rigid "Norge," the First Airship to Fly over the North Pole. At the Bottom—The Goodyear "Pony Blimp" a Small Non-Rigid Design.

transportation companies of large capitalization. The airship is a long range vehicle as they can stay in the air for thousands of miles travel and the airplane is the best for short range transport because its flying radius is limited by the fuel supply it can carry, unless pay load is greatly sacrificed.

The most practical machine, the airplane, depends upon the correct application of aerodynamical principles. Yet, while flying machines in a large sense may be said to include all devices that have contributed to assist man to fly, besides the use of the gas bag, the only form that has attained success is the airplane. This machine is capable of movement in any direction, as in a vertical or horizontal plane or any angular component of the two, by the aid of simply controlled members which are easily installed on the machine itself and actuated by the pilot.

There are three classes of flying machines. Those that seek to sustain themselves as birds do, by flapping wings, are known as ornithopters. Other types have been built in which a lifting action is secured by aerial screws, but few of these have been devised that have produced results sufficiently great to warrant further expensive or extensive development of this type. The third class includes the airplane and is the most practical. There are two main retarding forces to be overcome in securing successful mechanical flight, those having to do with gravity and others that are due to wind or air resistance.

Attraction of Gravity.—We will first concern ourselves with the attraction of gravity. Every mass of matter that is near the earth, if free to move, pursues a straight line toward the center of the earth, and the force by which this motion is produced is called gravity. At the same distance from the center of the earth the gravity of different objects varies as the mass. If a body is not free to move, its tendency to go toward the earth's center causes pressure, and the measurement of this pressure is called the weight of the body. Weight is usually employed as a measure of mass. The more the pressure of a body is towards the earth's center, the greater its weight. The body that is said to be the lightest is one that has the least gravity attraction. The attraction of gravity varies directly as the mass, the greater the mass the greater the force acting to bring it towards the earth's center; the nearer the earth's center the less the attraction.

A body 2,000 miles under the earth's surface would be attracted with only half the force that would obtain were it at the surface. It is at the surface of the earth that this force is greatest and at great heights it is less. For example, 4,000 miles above the earth's surface gravity is one fourth as much as it is at the earth's surface. At heights at which it is possible to carry on experiments the variation is very slight and may be regarded as negligible. It will be evident that one of the most important forces to be overcome in flying machines is the attraction of gravity, and considerable power will have to be utilized for this purpose alone.

Elementary Airplane Principles.—In order to secure a good understanding of airplane operating principles it may be well to mention that air planes of the biplane form of the present day are really developments of the box kite, and that comparisons can be made with well-known appli-

ances, such as the sails of boats, to make clear some of the principles upon which airplane flight is based. For simplicity of presentation we can consider the boat sail as an example to show the propelling force of the atmosphere in motion which, as previously outlined is termed wind. Any object which can be tensed or tightly drawn so that the wind will exert pressure upon its broadest area will create power in proportion to the velocity of the wind, the area exposed to the air pressure and the angle of attack of the wind. This, of course, means that the object or plane must be at approximately right angles to the relative wind to receive its full force which is not true of the lifting surface of an airplane, which is inclined in most airplanes at angles ranging from 2 to seldom more than 20 degrees as

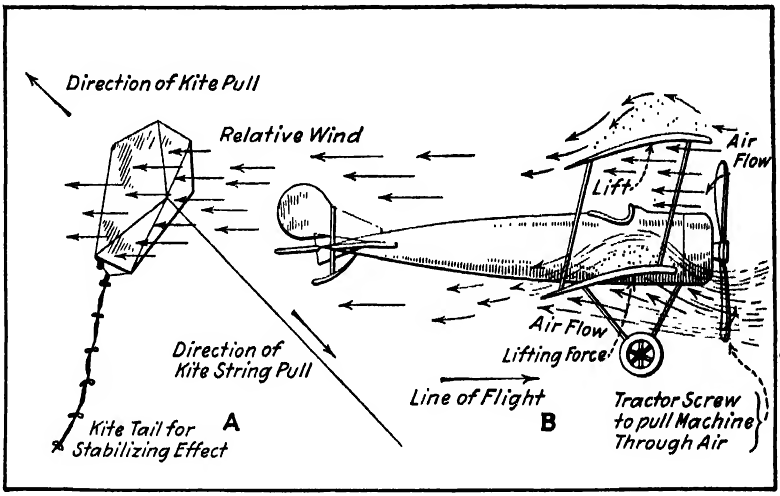


Fig. 4.—Diagrams Comparing Action of Wind on Kite and Air Pressure under Airplane Wings.

a maximum with the relative wind. Perhaps the most familiar illustration of wind power is the wind-mill, and the toy pinwheel is a device by which any child is capable of unconsciously observing that air in motion will create power or do work. All children who have flown kites know that the wind will lift a plane surface and those who have lost their toy balloons have become familiar with aerostatic principles early in life. Model airplanes propelled by rubber bands have also served to educate modern youth on elementary airplane principles.

Kite Supported by Air in Motion.—With the kite attached to the ground by a string and depending upon the velocity of the wind under its surface to elevate it, and a balancing device in the form of a tail to maintain steadiness, as shown at Fig. 4 A, we have one example of the use of air pressure to sustain weight. In the boat sail, which is capable of overcoming the resistance of the water on the hull by using the wind as a propulsive force, we have another example of how the wind may be made to do work, while in the airplane we have to a certain extent the principle of a box kite as far as its capacity for sustaining weight is concerned by air pressure.

Instead of being dependent upon the velocity of the wind as a kite is, an airplane is driven against the air by means of one or more aerial screws which are revolved by suitable prime movers, usually an internal combustion engine as shown in Fig. 4 B. This propulsive force is utilized for a

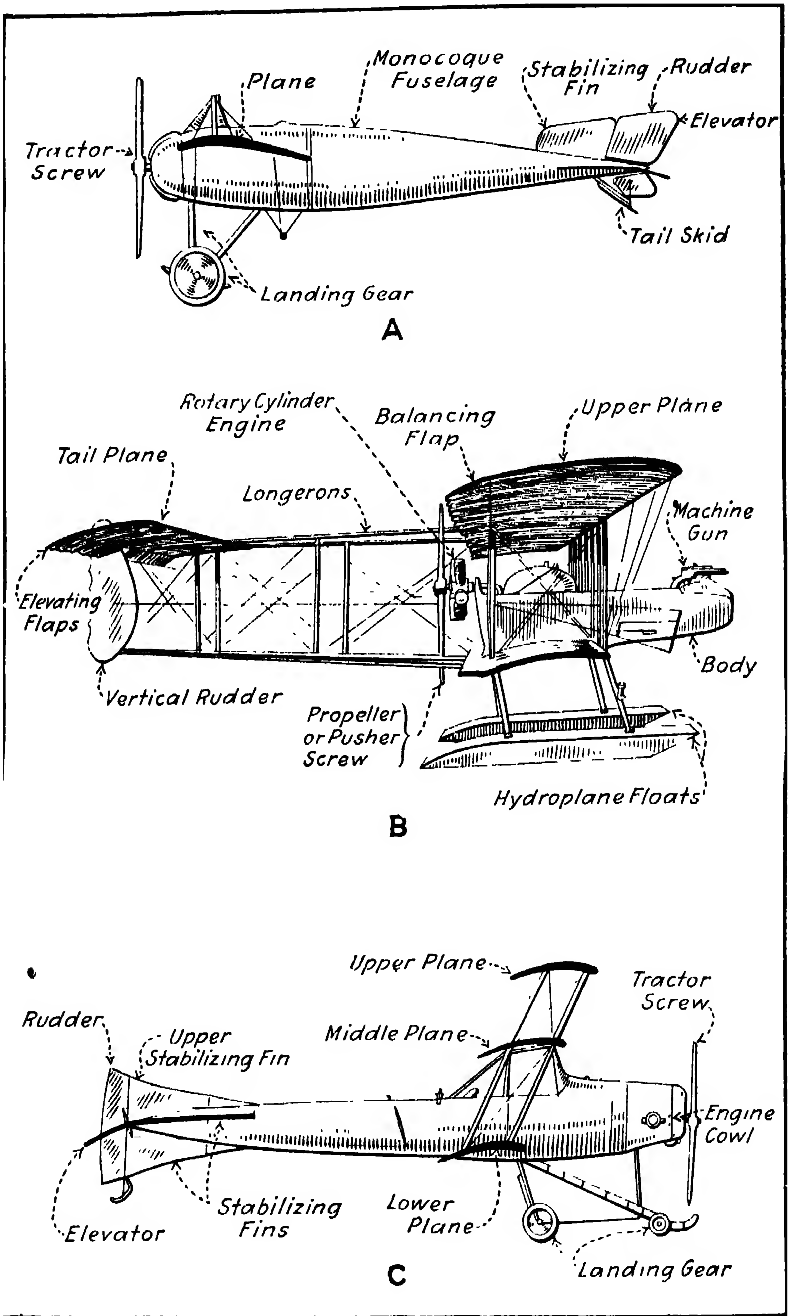


Plate 1.—Types of Early Airplanes. A—Monoplane. B—Biplane. C—Triplane.

twofold purpose. In the first place, to permit the direction of motion of the airplane to be independent of the wind direction and also to retain a sustaining force under the planes regardless of the direction of atmospheric flow.

It will be apparent upon reflection that if the kite is considered a reversed boat sail and then when again reversed an instance or illustration

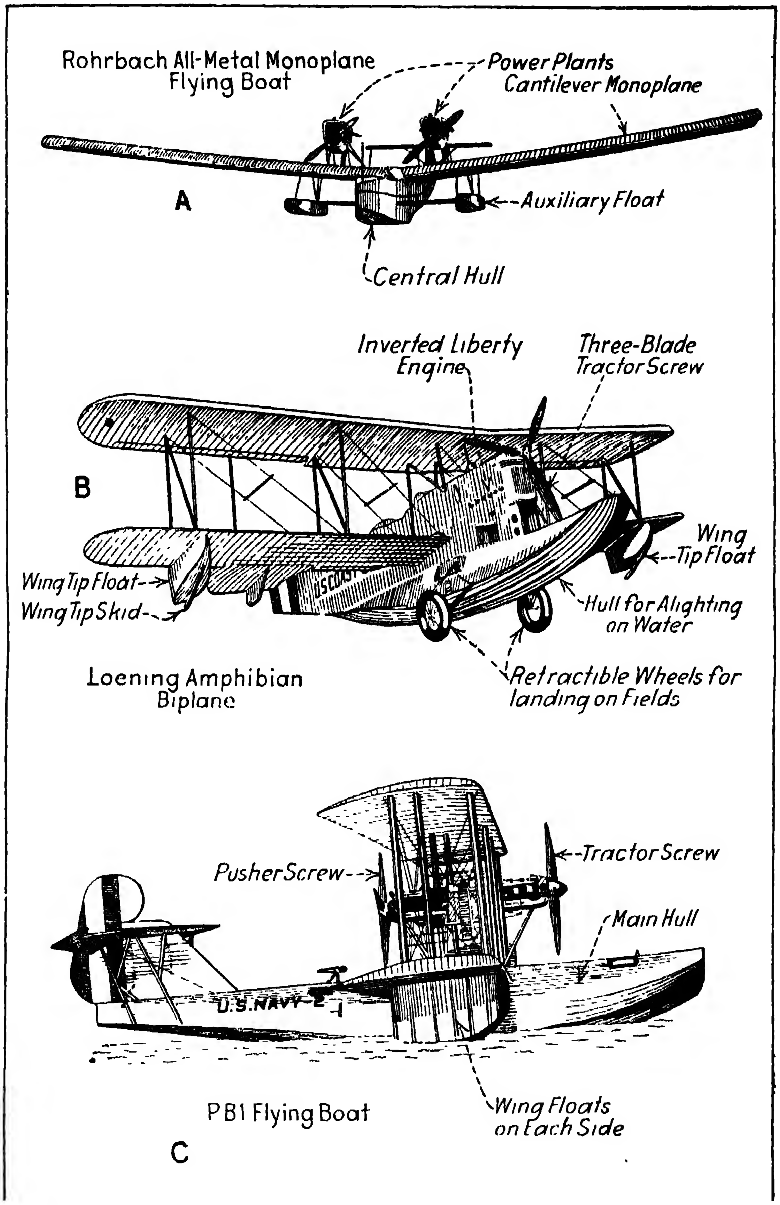


Plate 2.—Unusual Modern Aircraft Designs. A—The Rohrbach All-Metal Monoplane Twin-Engine Boat-Seaplane. B—The Loening Amphibian Biplane. C—Boeing P.B.I. Navy Flying Boat-Seaplane with Tandem Engines.

of the airplane supporting surface, it will be evident that in the three there is but one principle, though it is differently applied. In the same manner in which varying power may be secured by altering the pressure of the atmosphere on the sail of the vessel by changing its position, it will be seen that by varying the angle of the plane in the air that it is possible to vary the degree of sustaining effort. It is apparent that airplanes must be proportioned with a view of having minimum resistance to the wind, and it must reach this result without sacrifice of lifting effect or sustaining power. Wind tunnel experiments have brought out in an unmistakable manner the retarding influence of air resistance and in modern aircraft designs, especially in types designed to fly with small power or those intended for high speeds, the factor of air resistance and its reduction is carefully studied. There is a mass of technical data available to the student, and in a general treatise of this character all one can do is to outline a few of the elementary principles to give a basis for further research if the student desires to delve into the subject more deeply.

Air Resistance.—The factor of air resistance is a very important one which must be given careful consideration by the designer of aerial craft. It is of considerably greater moment than one would assume on first thought. The shape of the object being forced through the air (or, in fact, any other gas or fluid) will have material bearing upon the resistance offered to its passage. A "streamline" body has the least resistance.

Air resistance has been estimated to increase as the square of the velocity, so it will be seen that at ten miles per hour atmospheric resistance is four times what it was at five miles per hour; at 50 miles per hour, which is ten times the speed of five miles, the air resistance will be a hundred times as great. It has been found that air currents moving at the rate of 60 miles per hour have a pressure of approximately 17.7 pounds to the square foot, and from this basis the indication of almost any speed may be determined with reasonable accuracy. As an example of the ratio of increase of resistance with augmenting velocity, the following table, which gives the effort required in the horsepower to move a body through the air for each square foot of surface exposed at right angles to the relative wind, will prove of interest. In this case it is well to know that the horsepower required increases as the cube of the velocity, whereas air resistance augments as the square of the velocity.

TABLE I

Miles per Hour	Feet per Second	H.P. per Sq. Ft.
10	14.7	0.013
15	22	0.044
20	24.6	0.105
25	36.7	0.205
30	44	0.354
40	58.7	0.84
50	73.3	1.64
60	87.9	2.83
80	117.3	6.72
100	146.6	13.12

Resistance of Aerofoil Sections.—The resistance of plane or aerofoil sections is not nearly as great as that of spherical, cylindrical or rectangular bodies. To begin with, the planes are usually inclined at small angles to the relative wind, and seldom at an angle of more than 16 degrees, because in the ordinary aerofoil when this point is reached the lift becomes

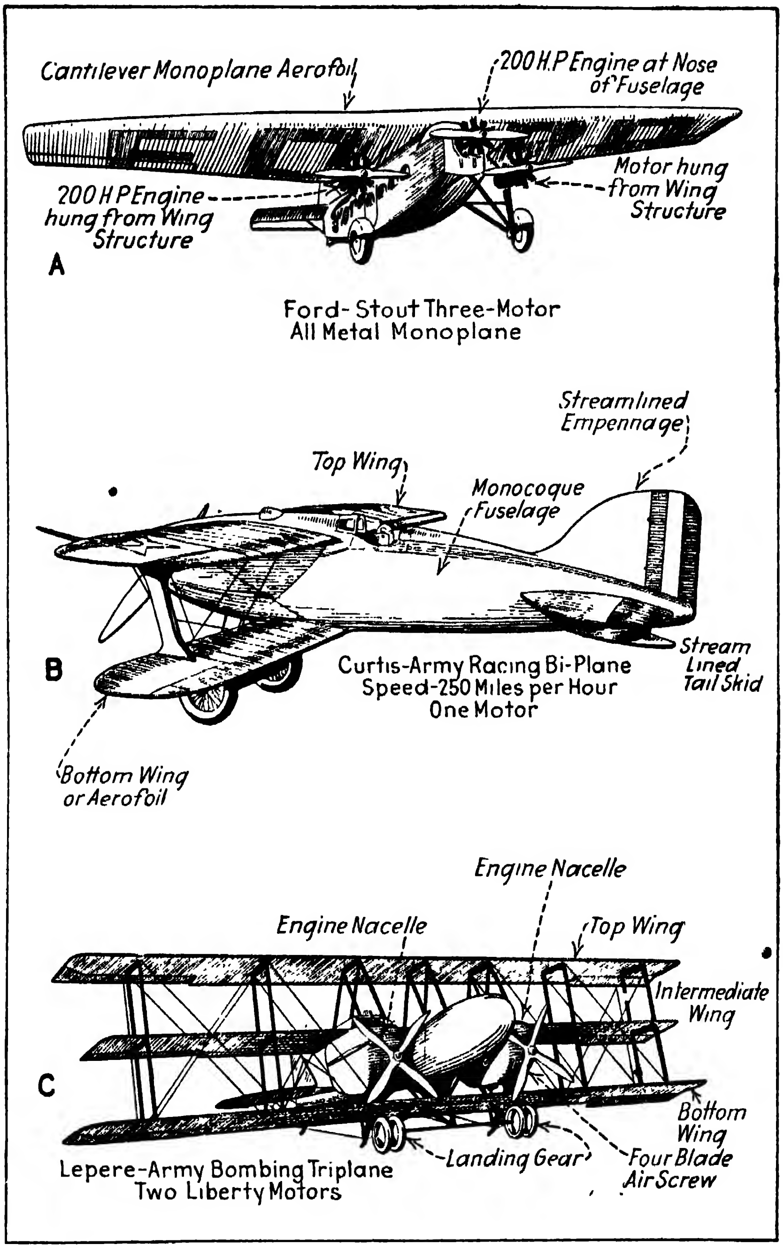


Plate 3.—Modern Heavier-than-Aircraft Designs. A—Ford-Stout Tri-Motor All-Metal Monoplane. B—Curtiss-Army One Motored Racing Biplane. C—Lepere-Army Twin Motored Bombing Triplane.

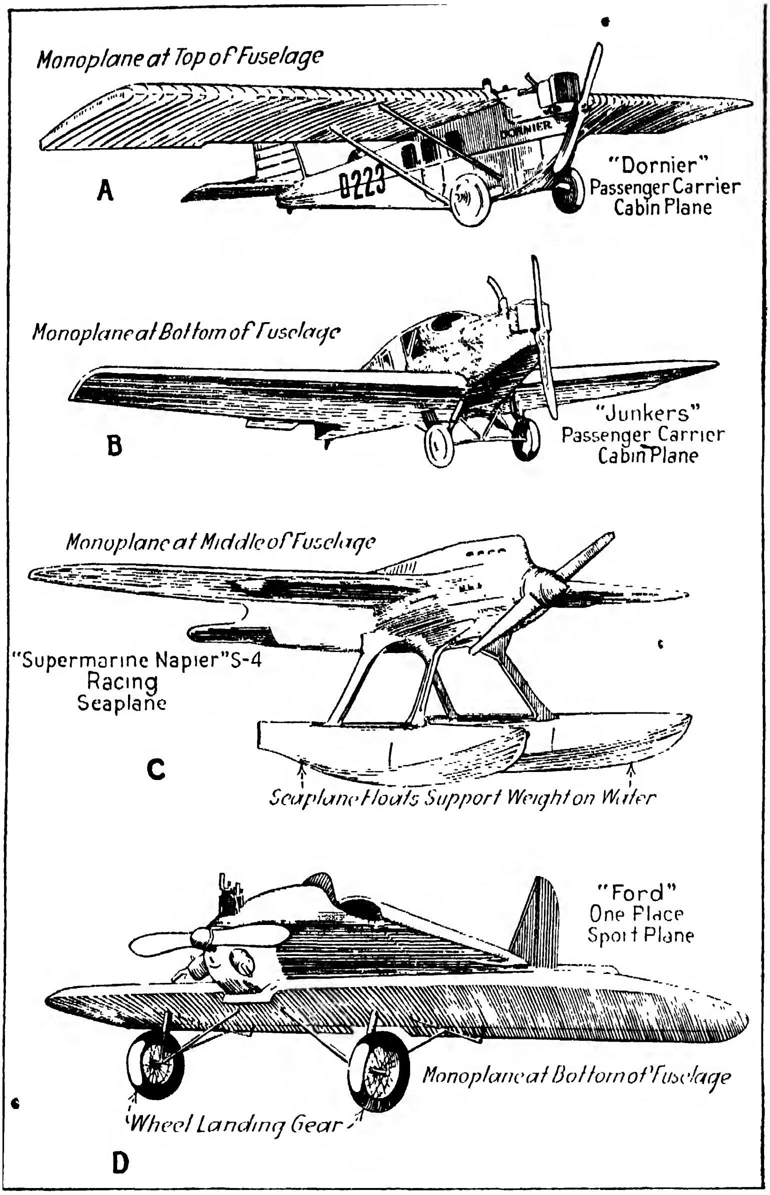


Plate 4.—How Monoplanes Differ in Design. A—Dornier Passenger Carrying Cabin Plane with Semi-Cantilever Aerofoil at Top of the Fuselage. B—Junkers Passenger Carrying Cabin Plane with All-Metal Cantilever Aerofoil at Bottom of Fuselage. C—Supermarine-Napier S 4 Racing Seaplane with Cantilever Aerofoil at Middle of Fuselage. D—Ford One-Place Experimental Sport Plane with Cantilever Monoplane at Bottom of Fuselage.

The amount of power required depends upon many factors, and as a general rule the greater the surface of the airplane for a given weight the less the speed that is necessary to drive it through the air to secure sustentation and the less the amount of power required to lift it from the ground.

The smaller the wing area, or the more the value of the wing loading factor is increased, the greater the motor power necessary to secure flight. Airplane design, the same as that of any other mechanical contrivance, is a series of compromises and the final form can only be derived at by a careful consideration of the many differing factors on which design is based.

How Airplanes Differ.—For this reason airplanes designed to carry heavy loads usually have a large surface, moderate power and relatively slow speed. High-speed airplanes have small surface and high-capacity power plants. Airplanes are made in three main types—the monoplane as shown at Plate 1 A, the biplane outlined at B, and the triplane as de-

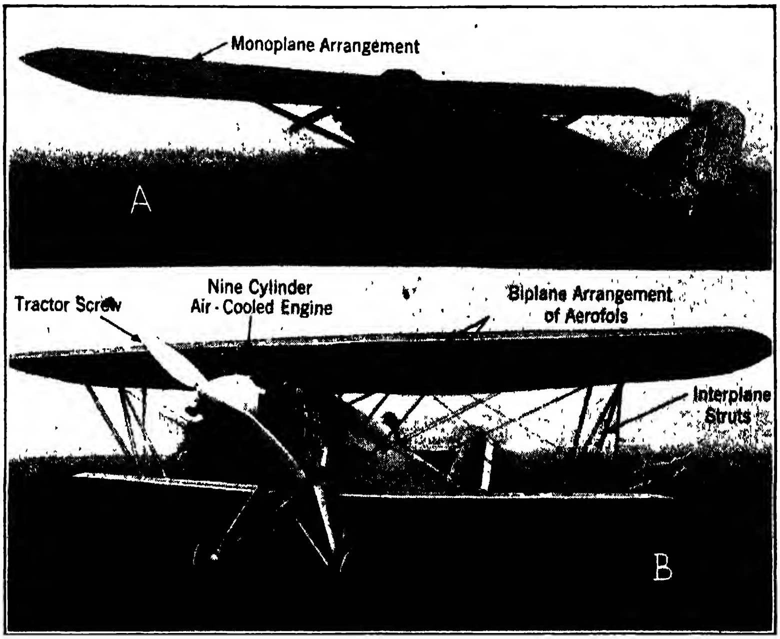


Fig. 6.—Modern Airplanes of Differing Design. A.—The Travel Air Cabin Monoplane. B.—The Curtiss Hawk Pursuit Biplane.

picted at C. If the machine has the air screw mounted in front, it is called a tractor; if the power plant and screw are mounted in the rear of the pilot as at B, it is called a pusher. Machines intended to rise from and alight on water are called "seaplanes" or "flying boats" to replace the clumsy term "hydroaeroplane" formerly used. The term "hydroplane" applies to strictly water craft without wings which skim the surface at high speeds but which do not actually leave the water as the rear part of the hull is immersed regardless of the speed. When the plane is provided with a central hull as in the Rohrbach monoplane and Boeing P B 1 seaplane shown on Plate 2 it is known as a "flying boat" though the generic term "seaplane" also applies. Types developed to alight on either water or land, such as the Loening are known as "amphibians." The pusher biplane shown at Plate 1 B is provided with floats instead of wheels. The

appearance of a fast one-place scouting or fighting plane is shown at A, Fig. 7. The conventional two-seater used in this country for training purposes is shown at B. The fast planes are capable of a speed in excess of 250 miles per hour, the latter will not fly faster than 120 miles per hour. There has been a marked improvement in general airplane design as can be seen by comparing the modern types depicted on Plate 3 and Fig. 6 with those shown on Plate 1 and Fig. 7. The Ford-Stout three motored passenger carrying monoplane has a high lift wing and is made entirely of metal. The Curtiss-Army racing biplane has developed speeds in excess of 250 miles per hour and shows how carefully streamlining is carried out

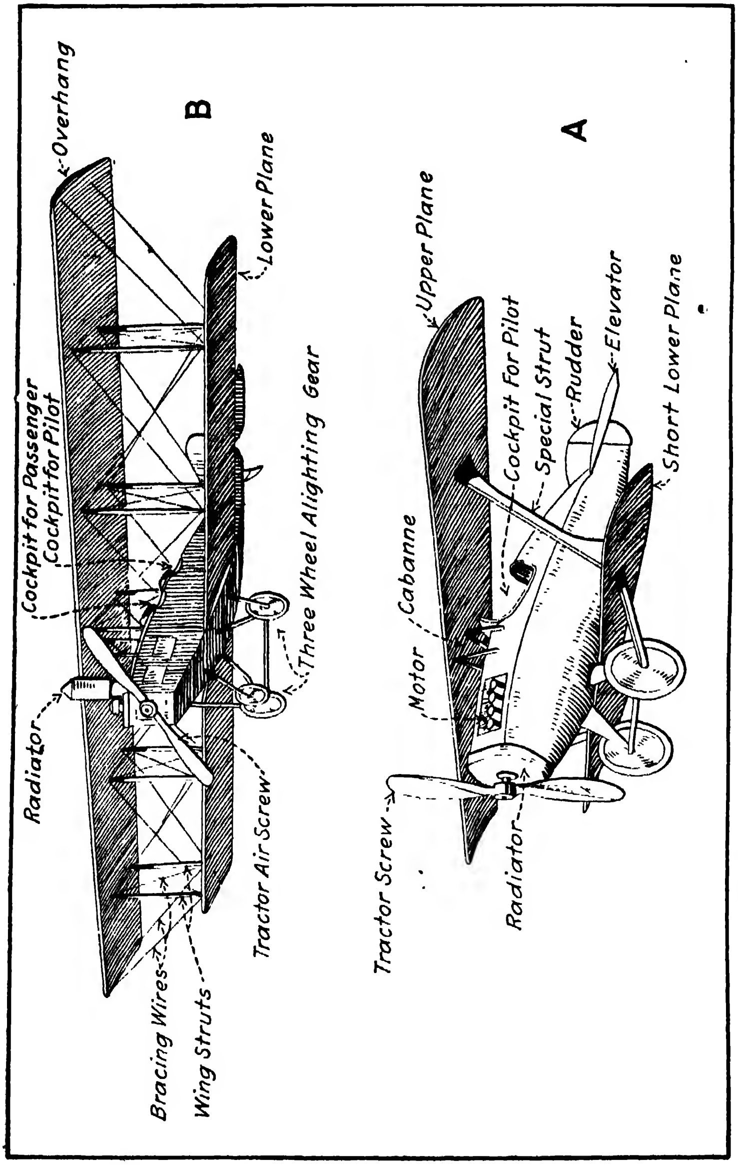


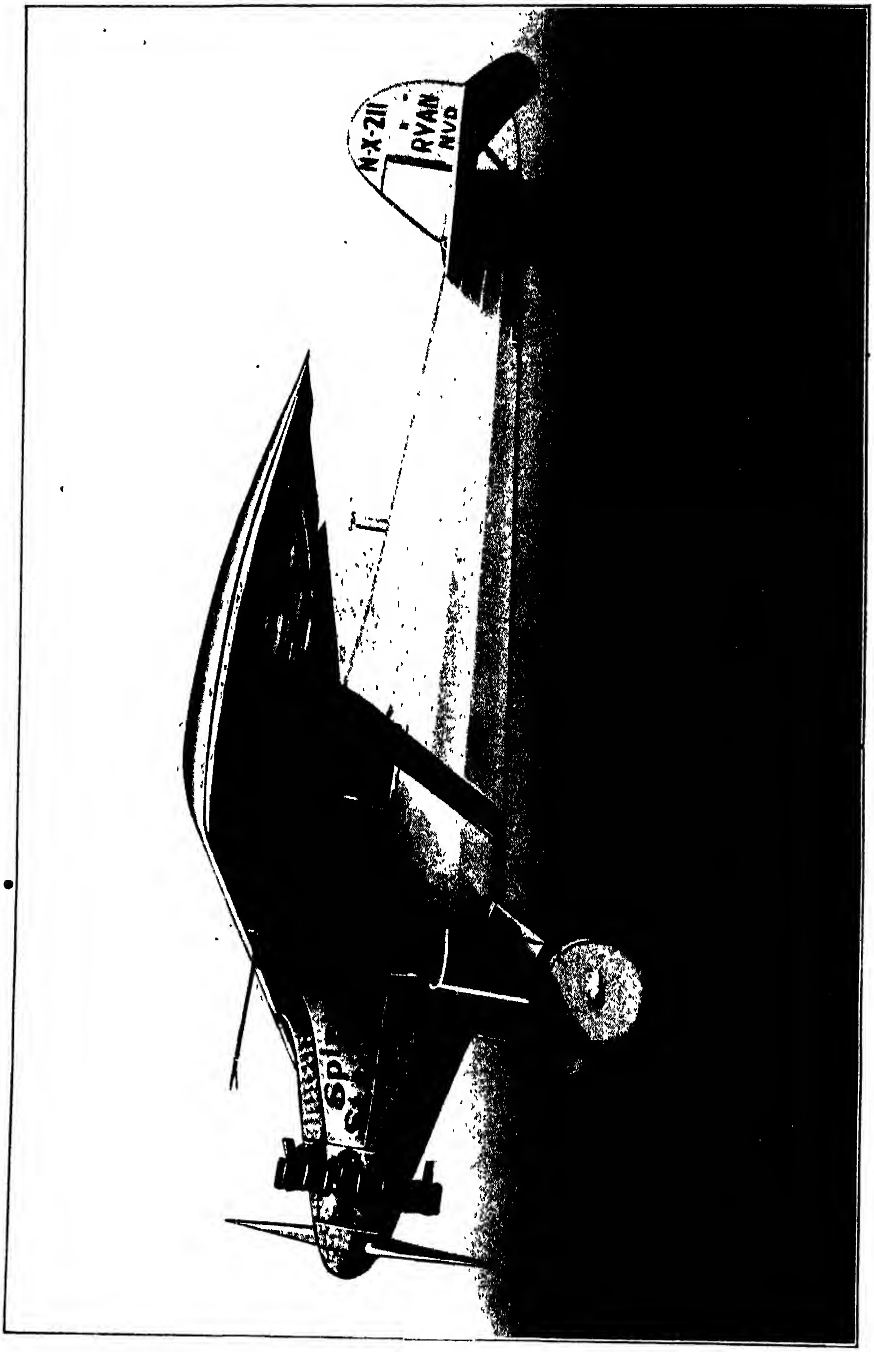
Fig. 7—How Biplane Designs Differ According to Work Required. A is a Small Surface, High-Speed, One-Passenger Pursuit Model. The Other, B, is a Large Surface, Medium-Speed, Two-Passenger Training Tractor of Early Design.

on modern designs. The Lepere-Army bombing triplane is a relatively modern example of large capacity, but moderate speed, multiplane structure for special duty.

Monoplane Development.—One of the most marked developments of the period following the World War is a growing appreciation of the merits of the monoplane construction and great improvements made in high lift cantilever wings have greatly augmented the strength and aerodynamic properties of single aerofoil airplanes. While this matter will be discussed more completely in a later chapter, a number of typical monoplanes of late design are illustrated on Plate 4. It will be observed that there is some difference of opinion among designers relative to wing placing. In the Dornier, the aerofoil is attached to the fuselage top and bracing members, extending from the bottom of the fuselage to the wing spars at a point about one-third of their length from the point of attachment of the aerofoils and main body, are depended on to take part of the flying and landing loads, i.e., these bracing members are subject to both tension and compression. The Dornier aerofoil is of approximately uniform cross-section its entire length.

In the Junkers monoplane passenger carrier shown below the Dornier it will be seen that the cross-section of the aerofoil varies, being thicker at the point of attachment to the fuselage, and becoming thinner towards the tips. The spars, in this construction are cantilever beams and are supported only at their roots or base. No external bracing is needed and parasitic resistance is reduced. The wing structure in the Junkers is carried below the fuselage. In the Supermarine-Napier S4 racing seaplane, the aerofoils are of the cantilever type and are attached to a part of the fuselage approximately on the horizontal center line or line of thrust. The aerofoil of the Ford one place sport plane, which is a relatively small machine powered by a three-cylinder air-cooled engine of about 30 H.P. is also of the cantilever spar types and is placed at the bottom of the fuselage.

There is still another method of monoplane aerofoil attachment where the wing is carried on a strut or "cabane" structure well above the fuselage, this being known as a "parasol" monoplane. As will be evident, the wide divergence in monoplane placing shows that considerable experimental work is being done to improve the general design. The elimination of struts and bracing wires makes for good streamline forms and marked reduction in parasitic resistance. The monoplane type, at this writing is responsible for the World's Seaplane Speed Record, the endurance record of 51 hours and 31 minutes sustained flight without alighting and is the first airplane to make a non-stop flight between New York City and Paris in a little over 33 hours for the distance of 3,800 miles. The monoplane type is also the first airplane to fly over the North Pole. The Fokker tri-motored plane piloted by Lieutenant Commander Byrd, U. S. N. made the polar flight and has also crossed the Atlantic Ocean from New York to the Coast of France with Byrd as Commander and Captain Bertram Acosta as pilot. A Bellanca monoplane, piloted by Bert Acosta and Clarence Chamberlain holds the endurance record and the New York-Paris flight, an epochal accomplishment, was made by a Ryan monoplane piloted by Captain Charles Lindbergh of St. Louis on May 20th and 21st, 1927.



The Ryan Monoplane Type NYP Flown across Atlantic by Captain Charles Lindbergh.

The airplane which Captain Charles Lindbergh used in his famous New York-Paris flight is a product of Ryan Airlines, Inc., and follows in general design the Ryan M-1 monoplane which has been used successfully in commercial service and air mail work on the Pacific coast. The NYP model which Captain Lindbergh flew has a span of 46 feet (10 feet greater than the

M-1) and a chord of 7 feet giving a total wing area of 319 square feet. The Clark Y aerofoil section is used as on the standard model. The engine is a Wright J-5-C which produces 223 b.hp. at 1,800 r.p.m. A duralumin propeller set at 16¼ degree pitch and made by the Standard Steel Propeller Co., is employed. The engine is air-cooled. The empty weight of the plane equipped with all instruments is 2,150 pounds as compared with about 1,100 for the M-1 model. The useful load totals 2,985 pounds and is made up approximately of 2,600 pounds fuel; 175 pounds oil; 170 pounds for pilot and 40 pounds miscellaneous. Thus the gross load at the start of the flight when fully loaded with gasoline was about 5,130 pounds while at the finish with all fuel used but with 10 gallons of oil left the total weight would be 2,415 pounds. The wing loading at the start of the flight was 16.1 per square foot; and the power loading 23.0 per b.hp. At the end of the flight with all fuel exhausted these factors would be 7.57 pounds per square foot and 10.8 pounds per b.hp. Calculated performances for the plane under full load are: Maximum speed 120 m.p.h., minimum 71 m.p.h., economic speed 97 m.p.h. at 1,670 r.p.m. Similar performances with fuel load exhausted are: 124.5 m.p.h., 49 m.p.h., and 67 m.p.h. at 1,080 r.p.m.

Under full load and at the economic speed with full rich mixture 6.95 miles per gallon are obtainable while 13.9 m.p.g. are possible with light load and lean mixture. At the ideal speeds of 97 m.p.h. at the start of the flight diminishing to 67 m.p.h. at the finish the maximum range of the ship is 4,100 miles while under practical flying conditions of 95 m.p.h. starting and 75 m.p.h. finishing speeds the range becomes 4,040 miles. In performance tests made on the NYP plane 129 m.p.h. was made over a measured 3-kilometer course with the plane carrying 25 gallons of gas and 5 gallons of oil. This is approximately equivalent to 124 miles per hour with full load of 425 gallons of gas and 25 gallons of oil. Distance of take off ranged from 229 feet with plane loaded to 2,600 pounds gross weight against a 7 m.p.h. head wind to 1,023 feet with load of 4,200 pounds against no head wind. Lindbergh is credited by the Geological Survey with having covered 3,610 miles on his non-stop flight across the Atlantic. On this basis he broke the non-stop distance record made last October by the French aviators, Rignot and Costes, who flew 3,313 miles from Paris to Persia. His time for the flight was 33½ hours and his average speed therefore was about 108 m.p.h.

Flying Not Inherently Dangerous.—Figures published by the Curtiss Flying Service, Inc., show that in flying 175,000 miles during 1925, carrying 4,000 passengers and training 60 student pilots, no one was injured and can be taken as indicating that ordinary flying, as distinct from "stunt" flying, when done by properly trained personnel in good, periodically inspected airplanes, need not be dangerous or compare unfavorably with other and older methods of transportation. Almost anyone of normal build and intelligence can learn to fly and the old idea that a pilot must be a super-man or hero must be relegated to that limbo where all of mankind's fallacious beliefs lie buried. Of course, a pilot who flies professionally can be compared to a railroad engineer, he must be specially trained. Of the thousands of amateurs who can be trusted to navigate small boats and yachts,

very few could be entrusted with the navigation of a liner. It will be the same in flying, there will be professional pilots, flying to earn their daily bread and amateur pilots, flying for pleasure. Those with special aptitude will become professionals, the majority will correspond to the average motorist or boatman, and will pilot small planes capable of carrying two or three people used for individual business or pleasure.

Good Pilots Essential.—If commercial flying is to be made an established industry the public must become "air-wise" just as it is now "motor-wise." Good pilots, capable of assuming responsibility comparable to that of a railroad engineer but having a superior technique because of the greater skill required in piloting and navigating aircraft will be needed in increasing numbers as aircraft increase in numbers and commercial applications. Commenting editorially on this subject, "Aviation" says:—

"There is one place where the new air lines cannot afford to economize and that is in respect to their pilots. As demonstrated by the Air Mail, a good pilot can 'get through' with an obsolete type of plane where a poor pilot would crash even the best of equipment. Good modern equipment is essential if an air line is to pay dividends but good pilots are more essential than anything else for all operations.

"The qualities which make a man successful in other occupations are more familiar and more obvious than those which make a successful pilot. A good pilot is as rare as a good business man and is just as valuable to the company for which he works. Some men have an extraordinary aptitude for flying, while others have acquired the ability to meet emergencies through long experience. Some men, though not extraordinary fliers, have an ability to 'get away with it' in case of an emergency. There are no tests that can show a pilot's working ability; his performance is the only thing which counts. The very best is none too good for the air lines. Maintenance of schedule is of vital importance and the pilot who can fly through thick weather or land his plane under circumstances where a poor pilot will crash will earn many times the extra salary which must be paid him.

"Concentrated attention has been focused on the development of air transportation such as exists in Europe, and progress in this direction is most important and valuable and has received the consideration of many of the ablest men in the industry. In the meantime, however, a very significant form of commercial flying has been developed in this country which has practically been ignored by many of those who have earnestly set themselves to the task of helping to create civilian aeronautics in the United States.

"While it appears reasonable to predict in commercial aeronautics a vast amount of air transportation, the importance of the extensive aerial service flying which has already been done, cannot be overlooked. In the planning of airports, in the legislation concerning flying and in the correlation between civilian and military flying, great consideration should be given to aerial service. If the men guiding the development of aviation ignore the aerial service flier they are ignoring one of the most vital phases of their work."

Possibilities of Aviation.—While at the present time, racing planes have shown speeds in excess of 250 miles per hour this has been done by the

sacrifice of many of the factors that will make commercial flying practical. It has been stated that we can look forward to airplane speeds of about 300 miles per hour with planes adapted to commercial work but such speeds will only be secured by flying in rarefied air at extremely high altitudes of from 30,000 to 60,000 feet or in the regions of no weather known as the stratosphere. This will call for special planes, propellers and power plants as well as having reliable means of making it possible for the passengers and pilots to breathe normally in the highly rarefied air. At this time, because normal flying has not been given prominence in the daily press and only accidents are considered as news, one can understand why the general public believes that flying is not only dangerous but also why relatively small use is made of flying outside of the Government services. Figures compiled by "Aviation" show that over 9,000,000 miles were flown by civilian pilots during 1925 and that this had been done without subsidy or government assistance of any kind. That aviation will become a factor in modern transportation and that much matter that is now carried by train or boat will go by air in the future is apparent to any one who can understand the great improvements that have been made in airplane construction, not only in the plane structure but in the power plants which are light, enduring and reliable in their latest forms. The subject of commercial aviation is so important that the writer has devoted a special chapter to this important phase of our flying activities. In a few years, transportation by air will be commonplace. If a person desires to get to his destination as quickly as possible, train or automobile travel will be too slow in the near future and only air transport will provide the required speedy voyage.

More than 23,000,000 miles were flown by civil and commercial airplanes in the United States during 1926, according to William P. MacCracken, Jr , Assistant Secretary of Commerce for aeronautics. In addition to this mileage on heavier-than-air craft, it is estimated that a total of 37,500 miles were flown by lighter-than-air craft during the year. Reports from scheduled air transport operators and operators engaged in sightseeing, exhibition, advertising, photography, crop dusting and other branches of aerial work indicated that about 23,310,355 miles were travelled by 1,536 planes if an average speed of eighty miles an hour was used as a basis of comparison, Mr. MacCracken stated.

If the army, navy and Coast Guard flying time were to be added to this figure the total American air mileage for heavier-than-air craft would be 48,586,492 miles, he said. Flying over eighteen regular airways, 194 planes maintained a scheduled mileage of 4,474,772 miles last year. Reports from all air operators indicate that 94,353 passengers were carried on planes free of charge. The number of paying passengers totaled 676,567. The total number of hours flown reported was 234,313 and pay freight carried amounted to 418,986 pounds. Reports to the Department of Commerce indicate that 4,466 students received training in aviation during the year.

Aviation and Insurance.—It has recently been announced in the press that the Traveler's Insurance Company, one of the largest institutions of its kind in the world, has made drastic revisions in its rules with regard to writing accident policies covering flying hazard. A thorough study made by experts employed by this company has established to the satisfaction of

the heads of the concern that the hazards of licensed commercial aviation are little, if any, greater than those which beset pedestrians or the occupants of automobiles. Basing its action on these recent surveys, the company announced that effective December 1st, 1926, the basic insurance will be paid without additional premium cost on approximately 80 per cent of the company's accident policies for any loss caused by any hazard of aviation while the insured person is riding as a passenger in a licensed airplane or dirigible balloon, operated by a licensed pilot, upon a regular passenger route between definitely established airports.

It is believed this action is to be the forerunner of many important changes in aviation insurance. The active participation of the Department of Commerce in commercial aviation, the system of licensing, inspection, and rules and regulations which are bound to follow, will make it easy for an insurance company to distinguish between flying with a licensed pilot in a safe, reliable, licensed airplane; and flying with an incompetent pilot, or in an obsolete, uninspected, or otherwise dangerous machine. Surely the accident statistics will quickly demonstrate that properly regulated flying is decidedly safer than riding in an automobile over any well used highway where traffic is practically continuous such as the Boston Post Road in New England, the Albany Post Road in New York or the Dixie Highway in the South.

Standard Definitions.—The following definitions are taken from Report No. 240, Nomenclature of Aeronautics, of the National Advisory Committee for Aeronautics and are reprinted from that publication to familiarize readers of this book with generally accepted terminology. These definitions are the result of careful study by special committees comprising civilian and military authorities. They will be presented at the end of each chapter. Such terms as apply to that specific subject will be given following the subject and a special chapter, in which all the terms will be placed in alphabetical order concludes this treatise and is given for ready reference. The reader is advised to look up any term used that he may not be entirely familiar with as soon as he encounters it, either at the end of the chapter where it is mentioned or in the alphabetical arrangement in Chapter 19, as by so doing he can easily acquire a complete aeronautical vocabulary and can use the correct terms intelligently.

General Terms

aerodynamics—The branch of dynamics which treats of the motion of air and other gaseous fluids and of the forces acting on solids in motion relative to such fluids.

aeronautics—The science and art pertaining to the flight of aircraft.

aerostatics—The science that treats of the equilibrium of gaseous fluids and of solid bodies immersed in them.

As an aeronautic term, it relates to those properties of lighter-than-air craft which are due to the buoyancy of the air.

aerostation—The art of operating aerostats.

aircraft—Any weight-carrying device or structure designed to be supported by the air, either by buoyancy or by dynamic action.

airport—A locality, either of water or land, which is adapted for the landing and taking off of aircraft and which provides facilites for shelter, supply, and repair of aircraft; or a place used regularly for receiving or discharging passengers or cargo by air.

airway—An air route between air traffic centers which is over terrain best suited for emergency landings, with landing fields at regular intervals equipped with aids to air navigation and a communication system for the transmission of information pertinent to the operation of aircraft.

The term "airway" may apply to an air route for either landplanes or seaplanes or both.

aviation—The art of operating heavier-than-air craft.

cross-country flight—A flight which necessitates leaving the vicinity of a regular landing field.

pilot—An operator of aircraft. This term is applied regardless of the sex of the operator.

Types of Aircraft

aerostat—A generic term for aircraft whose support is chiefly due to buoyancy derived from aerostatic forces. The immersed body consists of one or more bags, cells, or other containers, which are filled with a gas which is lighter than air. (Figs. 1 and 3.)

Syn.—LIGHTER-THAN-AIR CRAFT. Includes airship and balloon, q. v.

airplane—A mechanically driven aircraft, heavier than air, fitted with fixed wings, and supported by the dynamic action of the air. (Fig. 2), Plates 3 and 4.

glider—A form of aircraft similar to an airplane, but without a power plant.

helicopter—A form of aircraft whose sole support in the air is derived directly from the vertical component of the thrust produced by rotating airfoils.

kite—An aircraft heavier than air, restrained by a towline and sustained by the relative wind. (Fig. 4.)

ornithopter—A form of aircraft heavier than air, deriving its chief support and propelling force from flapping wings.

Types of Aerostats

airship—An aerostat provided with a propelling system and with means of controlling the direction of motion. When its power plant is not operating, it acts like a free balloon.

non-rigid—An airship whose form is maintained by the internal pressure in the gas bags and ballonets. (Figs. 1 and 3.)

rigid—An airship whose form is maintained by a rigid structure. (Fig. 3.)

semi-rigid—An airship whose form is maintained by means of a rigid or jointed keel in conjunction with the internal pressure in the gas containers and ballonets. (Fig. 3.)

The term "airship" is sometimes incorrectly applied to heavier-than-air craft either in full or as "ship." This is a slang use of the word and should be avoided.

balloon—An aerostat without a propelling system.

barrage—A small captive balloon used to support wires or nets which are intended as a protection against attacks by aircraft.

captive—A balloon restrained from free flight by means of a cable attaching it to the earth.

constant pressure*—A supply balloon arranged to maintain a constant pressure of gas in the moored or docked aerostat.

free—A balloon, usually spherical, whose ascent and descent may be controlled by use of ballast or with a loss of the contained gas and whose direction of flight is determined by the wind.

kite—An elongated form of captive balloon fitted with lobes to keep it headed into the wind and usually deriving increased lift due to its axis being inclined to the wind.

nurse*—Sometimes used to refer to a constant-pressure balloon.

observation—A captive balloon used to provide an elevated observation post.

pilot*—A small balloon sent up to show the direction and speed of the wind.

propaganda—A small free balloon sent up without passengers but with a device by which papers or documents may be dropped at intervals.

sounding*—A small balloon sent up without passengers but with recording meterological instruments.

supply*—A container made of heavy fabric employed as a portable means of storing gas at low pressure. It is usually too heavy to rise even if free.

triangulation—A small captive balloon used as a mark on which to sight in a triangulation survey.

Types of Airplanes

amphibian—An airplane designed to rise from and alight on either land or water. (Plate 2 B.)

biplane—An airplane with two main supporting surfaces placed one above another. (Plate 3 B.)

flying boat—A form of seaplane supported, when resting on the surface of the water, by a hull or hulls providing flotation in addition to serving as fuselages. For the central hull type, lateral stability is usually provided by wing-tip floats. The term "boat seaplane" is now obsolete. (Plate 2 C.)

landplane—An airplane designed to rise from and alight on the land.

monoplane—An airplane which has but one main supporting surface, sometimes divided into two parts by the fuselage. (Plate 4.)

multiplane—An airplane with two or more main supporting surfaces placed one above another.

pusher airplane—An airplane with the propeller or propellers in the rear of the main supporting surfaces. (Plate 1 B.)

*Note:—Forms of balloons marked by an asterisk are not, strictly speaking, aircraft but auxiliaries.

quadruplane—An airplane with four main supporting surfaces, placed one above another.

seaplane—Any airplane designed to rise from and alight on the water. This general term applies to both boat and float types, though the boat type is usually designated as a "flying boat." (Plate 2.)

shipplane—A landplane designed to rise from and alight on the deck of a ship.

tandem airplane—An airplane with two or more sets of wings of substantially the same area (not including the tail unit) placed one in front of the other and on about the same level.

tractor airplane—An airplane with the propeller or propellers forward of the main supporting surfaces.

triplane—An airplane with three main suporting surfaces, placed one above another. (Plate 3 C.)

QUESTIONS FOR REVIEW

1. Name the important layers of the atmosphere.
2. What is wind and how does its pressure vary with velocity?
3. Describe main types of aircraft and tell how an airplane differs from a lighter-than-air craft in principle.
4. What are the advantages of the airplane over other types of aircraft?
5. Outline main principles of airplane sustentation.
6. What is air resistance and how does it limit aircraft flight?
7. How is air resistance reduced and would it be desirable to eliminate it entirely?
8. What part of the airplane wing contributes the most lift and why?
9. Briefly describe main types of airplanes and tell how they differ.
10. What factor has been responsible for the marked development in monoplanes?

CHAPTER II

LIGHTER-THAN-AIR CRAFT

Spherical Balloon Parts—Hydrogen Gas for Military Balloons—Use and Nature of Helium Gas—Consumption and Cost of Helium—Control of Free Balloons—Spherical Balloons of Little Value in Military Work—Kite Balloons Best for Observation Work—Dirigible Balloon Types, the Zeppelin—Spheres of Economic Usefulness—Airplane vs. Airship—Influence of Size—Relation of Size to Weight Increase—Value of Water Recovery—Preventing Waste of Gas—Water in Exhaust Gas—Water Recovery Apparatus—Condenser Details—Temperature of Gases—Use of Ballast—Some Advantageous Features of Airships—Stays Aloft with Engines Stopped—Dirigible can be Controlled as Free Balloon—Depreciation and Cost—Dirigible Balloon Types, the Blimp—The Semi-Rigid Type, —The Pilgrim-Goodyear Blimp—A Metal-Clad Rigid Airship—Requirements of Metal Hull Structures—Metal-Clad Hull Construction—Material Used for Metal Airship Hull—Notable Airship Flights—Standard Definitions.

The reason why aircraft of the lighter-than-air type leave the ground is a simple one. It is known that there are a number of gases which are lighter than air, e.g., coal gas, hydrogen and helium. The amount of lift possible depends upon the "buoyancy" of the gas, which is the difference between its weight and the weight of an equal volume of air. If one has an understanding of the approximate buoyancy of the gas used as a lifting medium, it is very easy to compute the lifting power of a given quantity of this gas. A balloon with a capacity of 16,000 cubic feet of hydrogen, if it is filled at the sea level and at a temperature of 60 degrees fahrenheit, will lift about 1,000 pounds. This, of course, including the weight of the gas and the container; and a balloon capable of lifting 1,000 pounds would of itself weigh about 550 pounds; this means that the envelope or container, the net-work, the observation car and the equipment it carries, as well as the weight of the gas, are all considered. The lifting power of a balloon of the same size filled with coal gas would be no more than 600 pounds. It will be evident that to lift a given weight with coal gas that it will be necessary to use a container holding nearly twice the quantity that is needed to handle the same load with hydrogen gas. The ratio of lift between hydrogen and helium is more favorable, as a balloon that could lift 1,000 pounds inflated with hydrogen can lift 900 pounds inflated with helium. A convenient value to remember is that 1,000 cubic feet of hydrogen will lift 68 pounds.

Spherical Balloon Parts.—The parts of a spherical balloon are clearly shown at Fig. 8, and may be readily understood. At the top of the main container, which is made of some fabric chemically treated to prevent leakage of gas, is placed an escape valve which is kept seated by pressure of the gas from the inside, and which can be opened only by pulling a cord convenient to the aeronaut who is in the basket. This cord passes down through the bag and passes through the neck or "appendix" so it can be reached from the basket. The function of this valve is to permit of a certain degree of gas escapement, which can be controlled by the operator when it is desired to descend. As soon as the operator ceases to exert pres-

sure on the valve cord, the valve closes and prevents further escape of gas. It will be evident that when it is desired to descend from any altitude, that a decrease in the lifting power of the gas bag would permit it to settle to the ground. There is an open neck at the bottom of the gas bag called the "appendix" to permit the gas to escape when it expands, as it would do when coming into warm sunshine. The heat produces an expansion and increases the volume of the gas. It will be apparent that unless some means were taken for relieving this excessive pressure, that it might disrupt the gas bag; therefore, as the gas expands it rushes out of the gas bag through the open neck at the bottom. If for any reason the sun should be

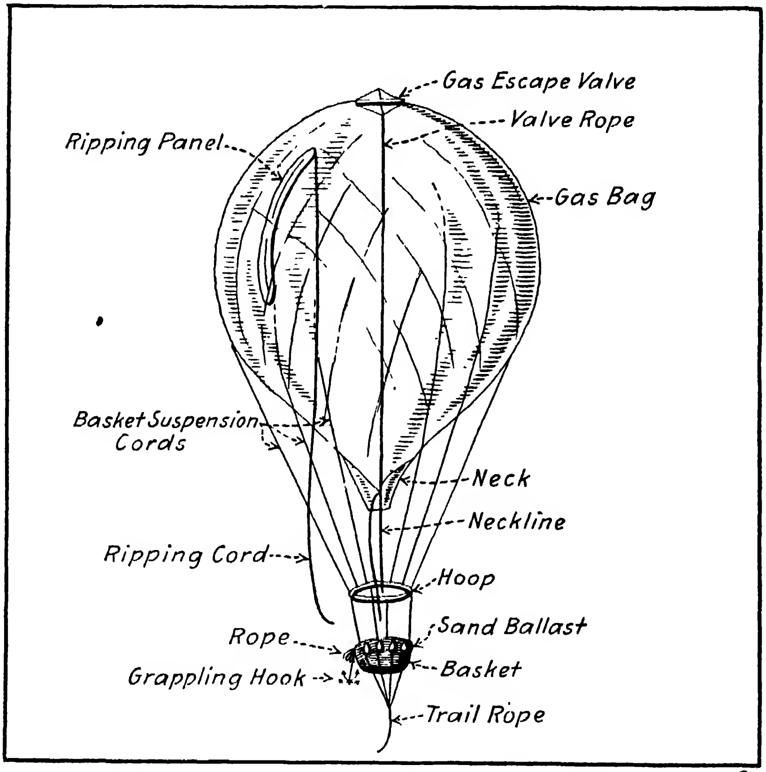


Fig. 8.—Simple Free Balloon of the Spherical Type with Parts Designated.

obscured by clouds or there should be considerable moisture in the air, the cooling of the gas will result in its contraction, and there should be a corresponding reduction in volume; the lifting power of the balloon is therefore impaired, inasmuch as the lifting ability is the ratio between the weight of the gas carried and the amount of air that it displaces. In order to keep the balloon from falling too rapidly, and to offset this condensation of the supporting gas, it is necessary for the aeronaut to throw off ballast, usually carried in the form of sand, until a state of equilibrium is reached and under which conditions the balloon will stay up as the decreased weight carried is proportionate to the lifting power.

When it is desired to make a rapid descent in order to avoid an ap-

proaching storm, or for any other reason, the escape valve is kept open until the balloon begins to settle, and when it has reached a point near the ground the operator will pull the ripping cord and tear away the ripping panel, which is normally sewed to the bag, in order to provide a large outlet for the sudden escape of gas. A grappling hook is carried to permit of securing an anchorage to any convenient tree or fence, and in addition a drag rope, which may be dropped for 100 feet or so below the car, is provided so that it may be grasped by people on the ground who might assist in bringing the balloon to a stop.

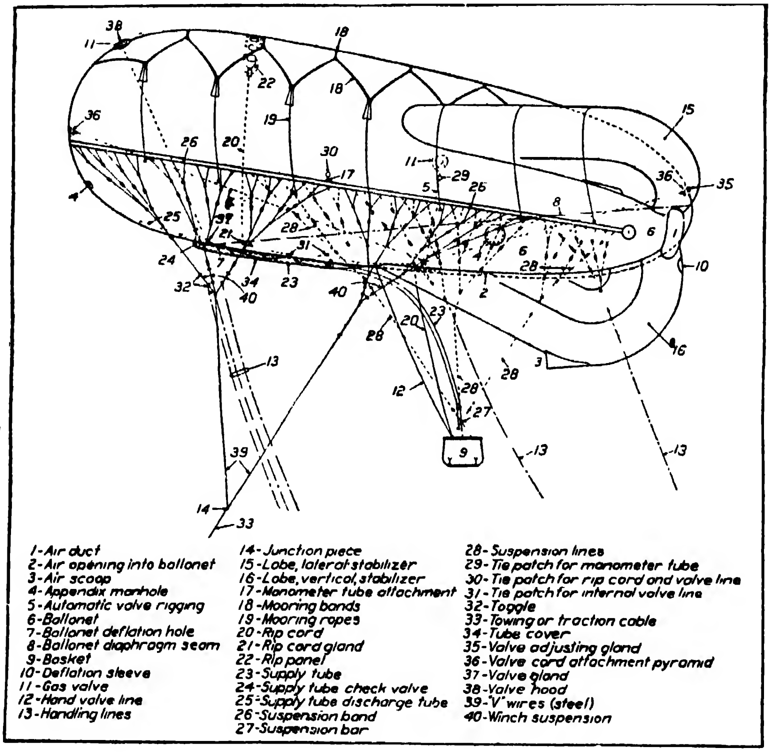


Plate 5.—Typical Modern Kite Balloon with Standard Nomenclature of Parts Recommended by the National Advisory Committee of Aeronautics.

Hydrogen Gas for Military Balloons.—Owing to the high cost of hydrogen gas, balloons that have been used for ordinary observation purposes at country fairs and used by individuals for exhibition purposes are filled with coal gas, but in all military ballooning the gas bags are filled from compressed hydrogen or helium stored in tubes. It will take about 5 hours to fill a large balloon with coal gas coming from a gasometer whereas when the hydrogen is carried in tubes in which it is held under high pressure, less than one hour suffices to fill the bag. Owing to the ease with which hydrogen may be carried when it is contained in steel tanks under pressure, it is always considered best for military purposes. Relatively simple hydrogen making plants have been devised which may be carried

in the field in the event of the supply of compressed hydrogen tubes giving out. In the early days, hydrogen making plants in which iron filings were acted on by sulphuric acid were used to generate gas for inflating.

Use and Nature of Helium.—The American military services are particularly fortunate in that helium is available for filling the gas bags of the captive balloons and dirigibles and that the United States is the principal source of supply for this valuable gas. Helium was discovered and experimented with about 30 years ago by the eminent British chemist, Sir William Ramsay, and its adoption by the United States authorities for the filling of airship envelopes is the first and only practical use to which it has been applied. Helium is the next lightest known gas to hydrogen and

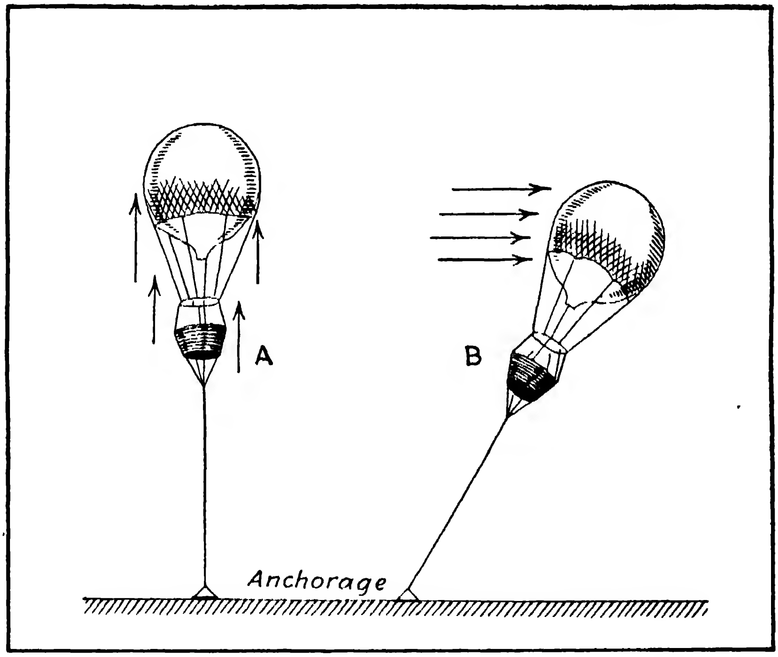


Fig. 9.—Why Captive Spherical Balloons are not Suited for Observation Work.

is remarkable as being the most inert of all the elements. It does not burn or support combustion; it has no taste, color or smell; and so far as is known, it does not enter into chemical combination with other elements. It is present in extremely small quantities in the atmosphere and is found mechanically retained in many mineral earths that are radioactive in character and particularly in thonanite, a mineral earth obtained from Ceylon. It is present in mineral springs and also in the natural gases that arise from wells in many parts of the United States and Canada. It is from this last source that the United States Government is obtaining the supplies for its airships. During the war it was frequently reported that the Germans were preparing to use it in their airships. Probably on account of the rarity of the sources of supply, the lack of knowledge as to its preparation on a large scale and the high cost of its production, it was never so used, a fortunate

circumstance for the populations of the Allied towns that were within reach of the activities of the Zeppelin raiders.

On July 1, 1925, pursuant to the act of Congress of March 3, 1925, helium production plant No. 1, near Fort Worth, Texas, with its contributing pipe-line, was transferred from the Navy Department to the jurisdiction of the Bureau of Mines. The Linde Company remained in charge of actual plant operations under contract with the Government but under the general supervision of the Bureau.

In this plant natural gas that comes through the Government-owned pipe-line from the Petrolia gas field, Clay County, Texas, about 104 miles north and west of Fort Worth, is processed for helium. The helium is removed from the gas by operation of a liquefaction cycle, and the gas minus the helium is then returned to the mains for commercial use.

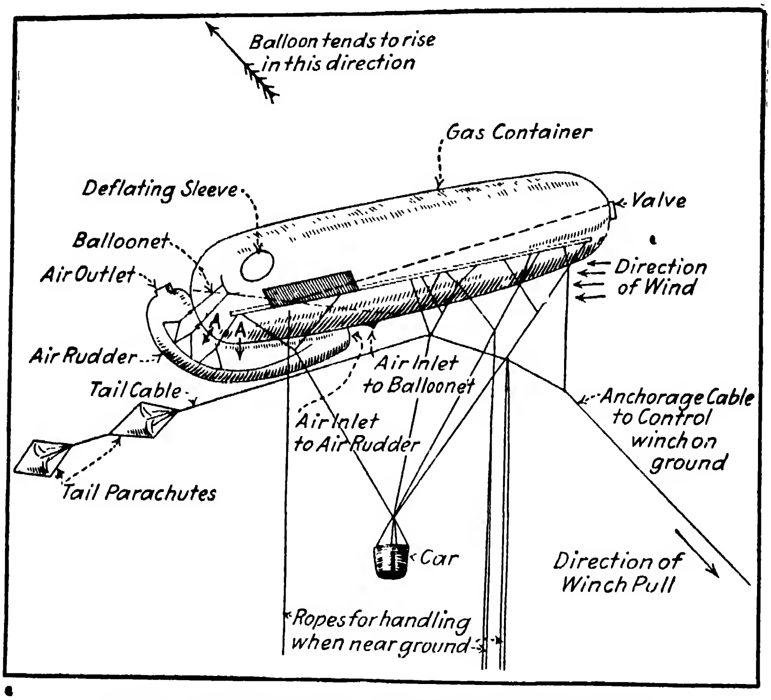


Fig. 10.—Parts of Typical Early Observation Balloon.

The first vital consideration in the Government's helium project is to provide adequate and constant supplies of helium-bearing natural gas, and to this end the Bureau has maintained a general survey of gas fields to discover and estimate possible sources of such gas.

Through use in airships, helium becomes contaminated by double diffusion; helium escapes through the walls of the gas cells and air enters through them. At certain intervals, therefore, the helium supporting an airship must be removed, purified and replaced. A plant for large-scale purification was designed and built at Lakehurst, N. J., for the Navy Department by the Bureau of Mines engineers. The process employed proved so successful that the Army decided to have a smaller mobile purification

unit that could be mounted on a railroad car and transported from place to place to serve airships. The Bureau of Mines undertook to design such a plant. Designs for a plant having one-fourth the capacity of that at Lakehurst were perfected, and a plant at McCook Field, Dayton, Ohio, was completed, tested and turned over to the Army for a final tryout at the end of April, the car being sent to Scott Field at Belleville, Ill., near St. Louis, for this purpose. This plant can purify 5,000 cubic feet of helium per hour for airship use, raising the purity from around 85 to about 98 per cent.

The American authorities commenced their experiments on its production in large quantities early in 1917, and by the autumn of the following year had erected a plant for its extraction from natural gases containing about 1 per cent of helium. The plant was found capable of producing about 8,000 cubic feet per day, at a cost of about 10 cents per cubic foot or roughly 20 times that of hydrogen. The process that was employed subjected the natural gas to compression, by which all the gases present, except helium, were liquefied. The helium passed over and was collected in suitable vessels. The process was in two stages, the helium obtained from the first stage having about 70 per cent purity, which in the second stage was increased to 92 or 93 per cent. It is now stated that either a new process has been devised or the old method so improved that in a single stage helium of sufficient purity for use in airships can be obtained at a cost of about 10 times that of hydrogen.

Consumption of Helium Gas.—Colonel A. Crocco, an Italian airship expert gives some valuable data on the consumption of helium gas and compares it to hydrogen as follows: The consumption of hydrogen gas in an airship is due (*a*) to osmotic diffusion, (*b*) to the necessary washings for maintaining a predetermined degree of purity and (*c*) to consumption during navigation. In the present state of technique and practical application, the most important of these three causes is the last, which in the case of the regular commercial traffic would assume very high values indeed. In almost all cases occurring in actual practice it has been found possible to compensate for the fuel consumption during navigation. Consequently the most important of the three causes that make the supply of gas for an airship a serious question is possible of total elimination.

Although it has not been possible as yet to ascertain sufficient data regarding the osmotic loss of helium through the different types of aeronautical fabrics, the experiments carried on at the Institute of Experimental Aeronautics at Rome and also in the United States show that it is not unreasonable to assume a loss of 3 liters per square meter (0.00978 cubic feet per square foot) in 24 hours. Basing our calculations on this figure the airship under consideration, which has a surface of diffusion of 18,000 square meters (115,251.1 square feet), would lose through osmosis 19,440 cubic meters (686,513.07 cubic feet) of gas per year, which is less than 20 per cent of its volume. The relative losses in the case of greater volumes would be even less due in part to the smaller surface-volume ratio.

At present the fresh supplies of hydrogen required on account of consumption during navigation are sufficient to maintain the necessary purity inside the envelope, but where fresh supplies are not available, the washing of the gas becomes a daily necessity, the importance of which is much

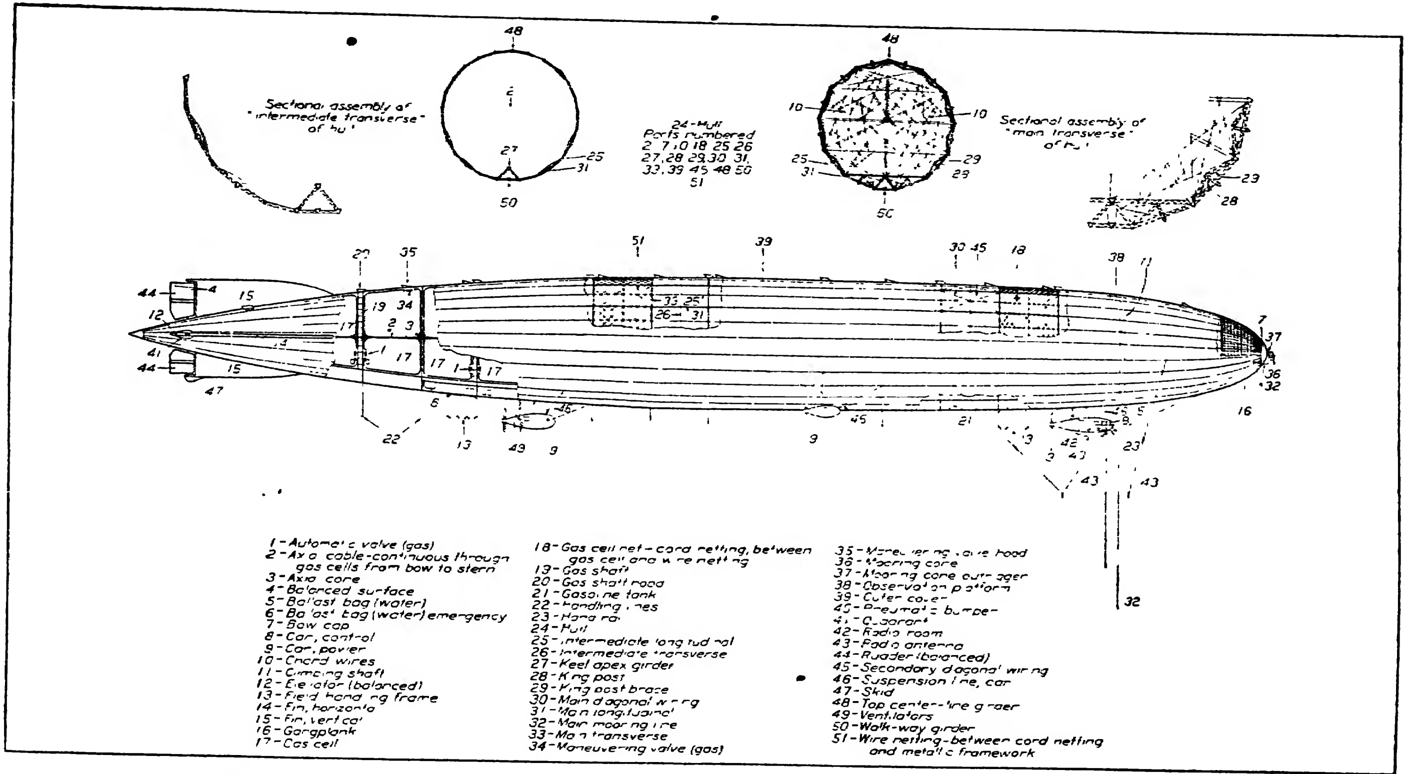


Plate 6.—Modern Rigid Type Dirigible Showing Standard Nomenclature of Parts Recommended by the National Advisory Committee of Aeronautics.

greater than the actual losses through osmosis. If, for example, it is desired to maintain a purity of 96 per cent with an annual osmotic loss of 20 per cent as calculated above, an annual washing equal to double the volume of the airship is necessary. In the case of helium this cause of great consumption can be totally eliminated by regenerating or repurifying the helium, that is, extracting the air that vitiates it, and by cooling and liquefying the gas.

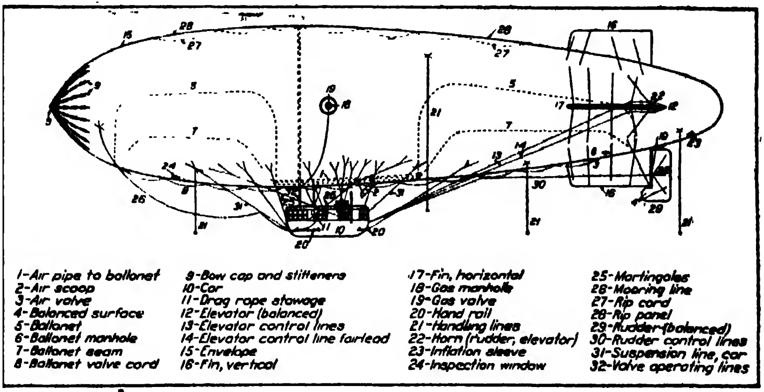


Plate 7.—Non-Rigid or Blimp Type Dirigible Balloon Showing Names of Parts Advised by the National Advisory Committee of Aeronautics.

Of the three causes mentioned that render the replacement of helium necessary, consumption during navigation, washing and osmotic loss, which are in the proportion of 100 to 10 to 1, only the last, which amounts to an annual average of 20 per cent of the volume of supply, cannot be eliminated. This has two important results. First, the necessity of replacement being reduced to this single cause, the available quantity of American helium is sufficient for running not one, but 150 airships of the average volume mentioned above, which is sufficient for a world fleet of civil airships; and second, the cost of helium is within the reach of economical navigation, because apart from the volume of gas necessary for inflation only an annual replacement of 20 per cent of this volume is required. In other words, the initial gas volume necessary for inflating the dirigible is exhausted in a minimum period of 2 years. Considered in this light, helium is no longer a material of consumption but a material of constructon of which the required initial outlay for the plant is amortizable in 5 years. Therefore, its substitution for hydrogen in civil enterprise is possible and economically profitable.

Control of Free Balloons.—It will be noted with a free balloon that there is no movement of the balloon relative to the air, as is true of an airplane or dirigible airship. A balloon must move with the air currents in which it is supported. The only control the aeronaut has over the movements of the balloon is to vary its altitude and attempt to seek air currents or winds flowing in the direction in which he wishes to go. The material ordinarily used for making gas bags is rubberized silk, though treated cotton has been employed. The balloon is surrounded by a netting of

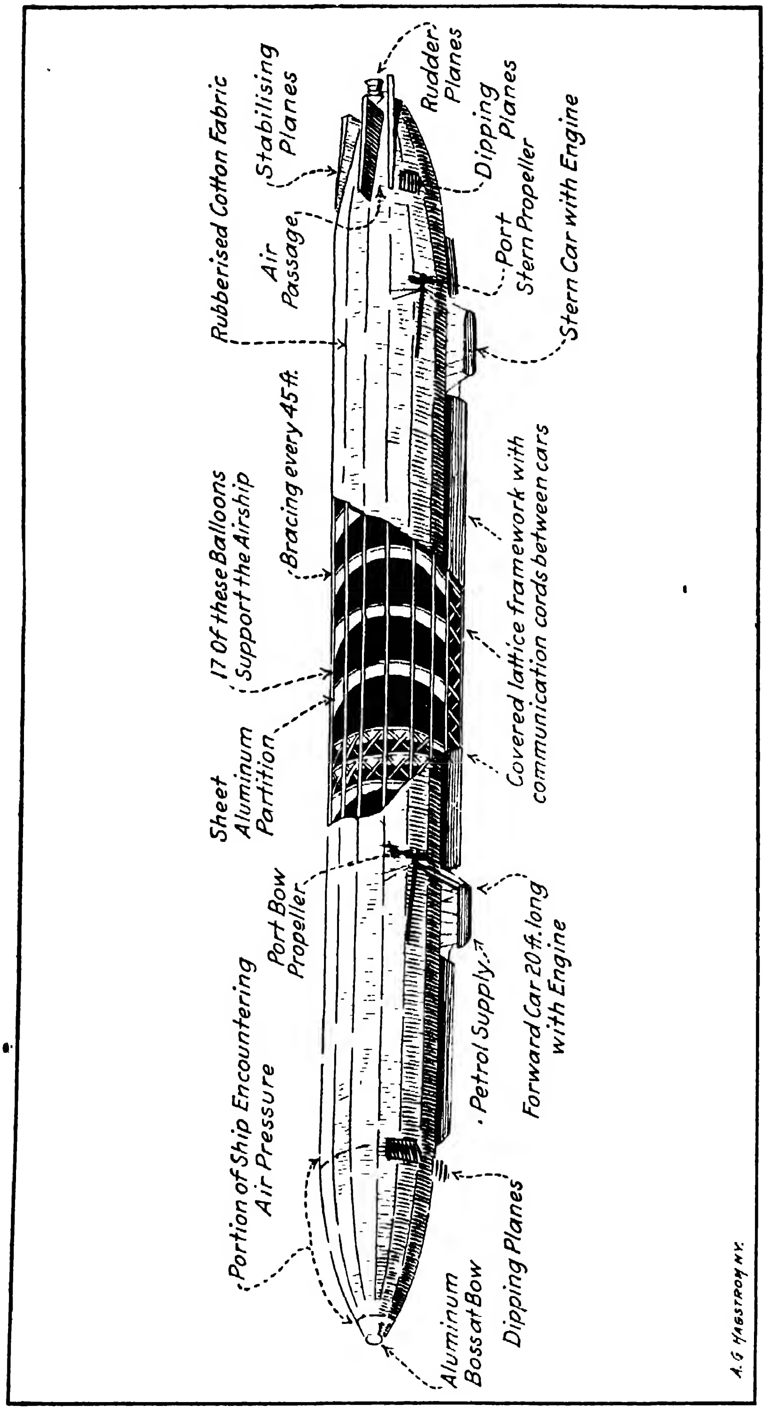


Fig. 11.—Part Sectional View of Early Zeppelin Airship.

Dirigible Balloon Types—The Zeppelin.—For offensive and observation purposes the Zeppelin type of airship received considerable use by the Germans. The Zeppelin airship depends upon numerous independent gas bags ranging in number from 18 to 23, which are held in a lattice work frame of aluminum alloy metal, so as to form a cylinder with conical ends having from 16 to 20 sides when viewed as a cross-section; each of the gas bags has the usual form of deflating valve and also is provided with an automatic safety valve to permit the escape of gas from the bag if the pressure becomes too high. The capacity of some of the early Zeppelin types varied from 800,000 to 1,200,000 cubic feet, and the dimensions ranged from 450 to 550 feet in length. The diameter varied from 40 to 50 feet. Modern forms have been built that are of over 2,000,000 cubic feet capacity while there are projected types authorized in England and the United States that will hold from 5,000,000 to 6,000,000 feet of gas and airship experts talk glibly of aircraft of that type that will hold 10,000,000 cubic feet of gas and that could circumnavigate the earth without refueling. The U. S. Navy airship, the Shenandoah was 680 feet long and had a capacity of 2,250,000 cubic feet of gas. A number of gondolas or cars are attached very close to the framework carrying the gas bags, and have double bottoms and are provided with shock absorbers so that the Zeppelin may descend on both land and water. The rigid type of construction permits of much greater speed than can be secured with the "Blimp" design, because the shape of a non-rigid varies to a degree as the pressure inside of the bags varies. The external form of the Zeppelin an early form of which is shown at Fig. 11 while a more modern section is given on Plate 6, which is regulated by the interior framework construction, does not alter its shape. Another thing is that the Zeppelin does not depend only upon the lift of the gas it contains for ascent and descent, but it is provided with horizontal rudders or elevators which can be made so the bag is tilted upwards to give a certain lift when the ship is propelled in a forward direction by its motors. A balloon rises statically while a dirigible obtains considerable of its lift dynamically.

The long under-surface of the airship itself also acts as an elevator as it is driven at high speed through the air. Owing to the relatively small size individual gas bags the Zeppelin airship does not need "ballonets," as the gas expansion is taken care of by the automatic valve. Between the gas chambers and the framework is a space which was filled with non-combustible gas in the war craft in order to serve as some protection from fire. Another thing—this inert gas tends to shield the hydrogen gas to some extent from changes of temperature. These airships are usually provided with water ballast and use a number of high-powered engines for propulsion. Four propellers were used on the early types these being attached to the framework of the airship and driven from the engines carried in the cars by means of gearing. The Zeppelin is capable of attaining speeds as high as 60 or 70 miles per hour against mild winds, and as it is provided with stabilizing planes and other surfaces that act as elevators to raise or depress the airship, it can be readily controlled without the loss of gas inevitable in balloon control. The gas bags are in place inside of the framework; the entire frame assembly is covered with a special fabric which is coated with an aluminum powder compound to increase heat radiation and to reduce

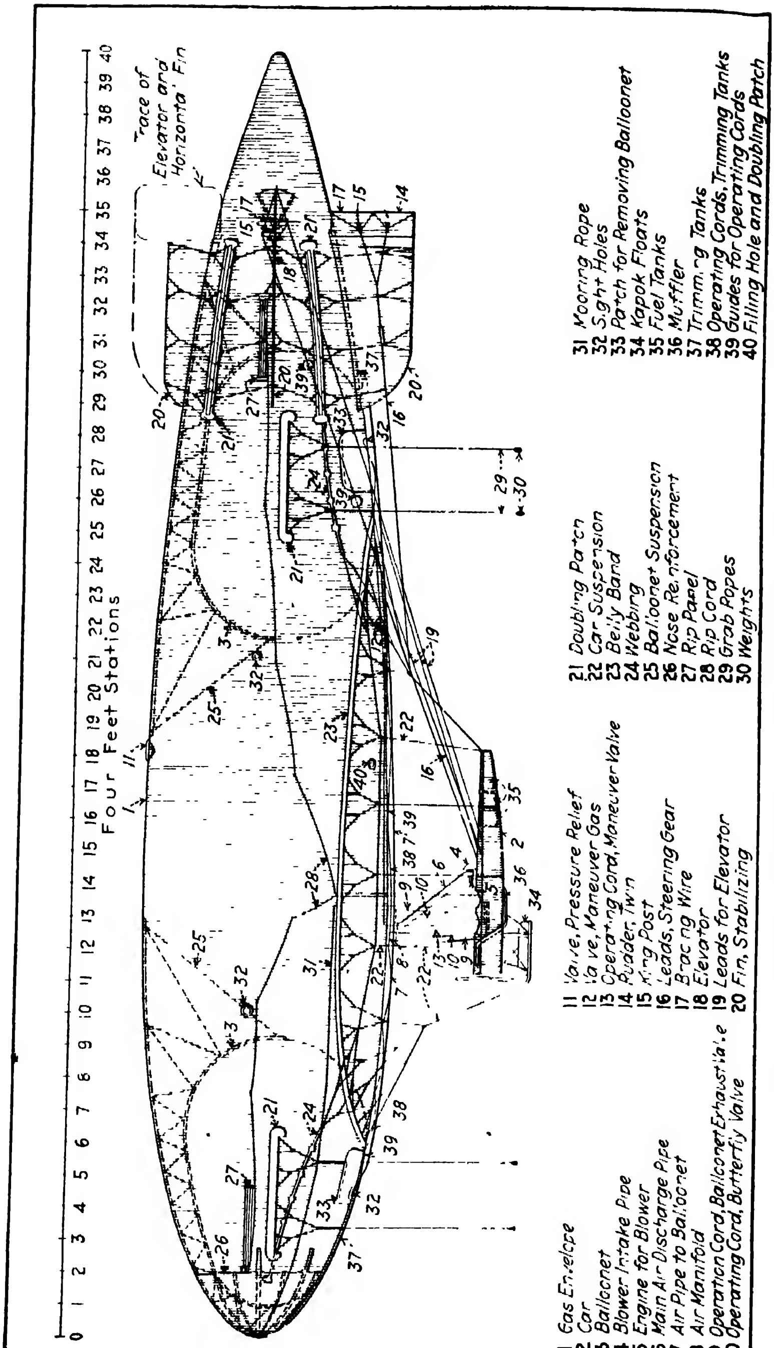


Fig. 12.—General Arrangement Plan for Early Type Navy "Blimps."

the risk of fire. The Zeppelin or rigid type dirigible, however, owing to its large size, is very vulnerable and is much easier to hit with anti-aircraft guns than faster and smaller airplanes are and for that reason, when used in offensive operations they are operated at night and fly very high. Modern types have the engines carried in power cars suspended from the hull, each engine driving a propeller geared to it and operated by a suitable clutch mechanism. In cases where the engines are not of the reversible type, reverse gearing may be used so the screws may act either as tractors or pushers as desired when manœuvering.

Spheres of Economic Usefulness.—It is difficult to make any direct comparison between the airplane and the airship because of the great dissimilarity in construction and any discussion on the relative spheres of economic usefulness must be largely predicated on performance per unit cost. Mr. H. F. Parker, in a paper read before the Society of Automotive Engineers has gone very thoroughly into this subject and while the paper in it entirety is available to students in the publications of the Society, the following abstract and excerpts from the S. A. E. Journal will indicate the thorough manner in which this authority on lighter-than-air craft has covered a difficult subject.

Although the generally accepted spheres of usefulness of the airship and the airplane are usually based on their comparative ranges of operation and their speeds, the suitability of either of these types for a given purpose is primarily dependent on two classes of factors, those fundamentally dissimilar and those roughly similar. Conclusions as to relative usefulness should be based on a consideration of the dissimilar characteristics, which include aerodynamic efficiency, size and comfort. Aerodynamic efficiency governs range and, since it determines fuel consumption, influences the cost of operation. The size required depends on the paying loads that are available for carrying. Comfort concerns passenger-carrying only.

As the propeller efficiency, rate of fuel consumption and ratio of weight of fuel carried to gross lift are similar in both types of aircraft, the range must depend on the L/D factor, that is, the ratio of gross lift to thrust. Although it is not customary to apply this ratio to airships, comparative curves for the airplane and the airship on this basis show a surprising superiority for the airship, not only at speeds of 60 or 70 m.p.h. but at higher speeds that have not yet been attained. In the matter of fuel consumption, an airship of 150-ton capacity travelling at 70 m.p.h. requires only one-quarter the fuel per ton-mile, and at 105 m.p.h. only one-half the fuel per ton-mile that is needed to propel 1 ton of airplane 1 mile at either speed.

Partly nullifying the advantage of the airship in the past because of lower fuel-consumption has been the waste of lifting-gas that occurs in maintaining equilibrium when the weight has been reduced by the consumption of fuel. Notwithstanding this waste the airship can still compete with the airplane on an equal basis in the matter of fuel consumption at a speed of 70 m.p.h.; but through water-recovery and hydrogen-burning the waste is no longer necessary.

In an airship flight, as the supply of oil fuel is consumed, a corresponding amount of hydrogen must be released, and it thus becomes of impor-

tance to determine whether this waste hydrogen may be utilized to replace a portion of the oil fuel supplied to the engine. The proportion of fuel gas admitted with the air must, of course, be kept sufficiently low so that no explosion can take place when the mixture is compressed in the engines operating on the Diesel principle which are now being experimented with, but no such limitations are imposed on the supply to engines of the Otto cycle type which are now generally used and in which electrical ignition of the compressed charge is employed rather than ignition by thermal

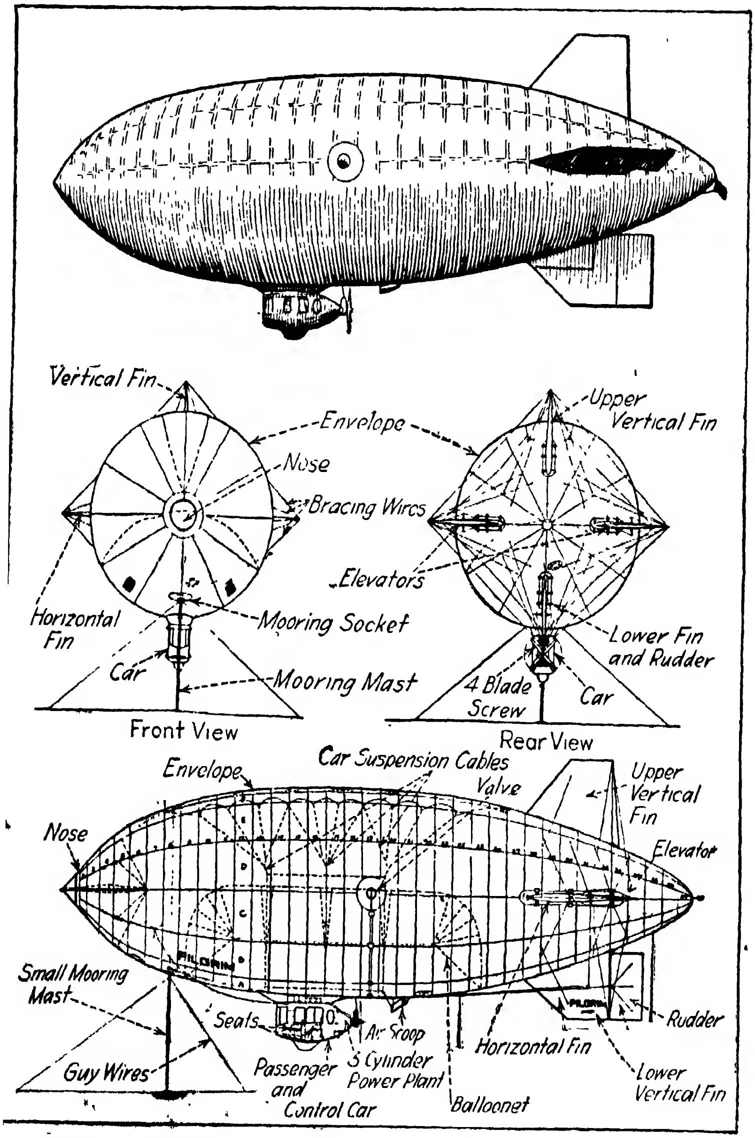


Plate 9.—Diagrams Showing Construction of Goodyear Pilgrim Non-Rigid Dirigible of 50,000 Cubic Feet Capacity.

means. In connection with the investigation of the practicability of the oil engine for the propulsion of aircraft which has been made for the British Air Service, some experiments have been made in regard to the effect of admitting small quantities of hydrogen and of coal gas with the air, and also on the effect of reduced air intake pressure on the performance of an oil engine. A paper on these tests was presented before the Institution of Automobile Engineers and the Royal Aeronautical Society by G. F. Mucklow, M. Sc. The engine used in the tests was a Crossley single-cylinder, solid-injection, heavy-oil engine of 14 inch bore and 23 inch stroke, having a volumetric compression ratio of 10.3 to 1 and being rated at 66 hp. at 211 r.p.m.

No ill effects of any kind ensued from the use of gas, nor were any indications of pre-ignition or detonation experienced, and it was found that when any appreciable quantity of either coal gas or hydrogen was being admitted, the engine appeared to run more sweetly. The following conclusions are drawn from the results: Small quantities of hydrogen or coal gas can be employed as an auxiliary fuel in a solid-injection oil engine. When gas is being admitted the engine appears to run more sweetly than when the same power is being developed with oil alone. No ill effects are produced by the use of gas beyond a slight reduction in the thermal efficiency and a slightly hotter exhaust.

With an amount of hydrogen equal to 3 per cent by volume of the air supply to the engine, the reduction in brake thermal efficiency at the highest load dealt with (53.4 b.hp.) is 5.3 per cent of the normal efficiency, while the corresponding reduction at the lightest load (24.4 b.hp.) is 10.9 per cent of the normal efficiency appropriate to this load. There are indications that as the amount of hydrogen admitted is increased, the thermal efficiency approaches a minimum value, after which it is suggested that the efficiency would again rise as the proportion of hydrogen to air became such as to ignite spontaneously at the compression temperature and pressure. Obviously, when helium is used for inflation, it cannot be burned and the excess lift due to fuel consumption and reduction of weight must be compensated for by water recovery apparatus.

Influence of Size.—With regard to size, consideration is given to the effect of dimensional laws on the dead-weight of both types of aircraft. Assuming that the dead-weight of airplanes increases with the increase in size under the 3/2 law, the further assumption is made that 10 tons is the weight at which the law beings to operate; in airships, the factors operating are different from those of airplanes and do not become effective until sizes are reached far in excess of those contemplated at present. Asserting that airplanes and airships of the same size are not likely to come into direct competition, Mr. Parker then examines the fields in which each type is likely to prove useful. Among the conditions affecting the comfort of passengers are found to be the relative amounts of space available on the two types of craft, and the various motions encountered, such as rolling, pitching, bodily vertical motion, and vibration.

But the observations made from the standpoints of aerodynamic efficiency, size and comfort, are said to be subject to modification by additional factors, of which the most important are (*a*) initial percentage of

useful load, (*b*) initial cost per unit of gross weight, (*c*) relative operating-costs, (*d*) insurance and safety, and (*e*) rate of depreciation, each of which is discussed in detail.

The conclusions reached are that, on account of aerodynamic superiority, the airship will be used wherever possible for carrying passengers in comfort, but a large field exists in which it cannot be used because of insufficient loads; that the airship will continue to be a long-range, the airplane, a short-range vessel, but these distinctions will be affected largely by the volume of traffic available; that although the cost of transportation per ton-mile is greater by airplane than by airship, this fact will not seriously limit the use of the airplane within its own field, the comparative magnitudes of the fields of heavier-than-air and lighter-than-air operation being similar to those of rail and water transportation; and that, inasmuch as the two types are complementary, the successful operation of either one will react to the benefit of the other.

Relation of Size to Weight Increase.—In developing his discussion, Mr. Parker outlines the dimensional law that seems to limit the size of airplanes. He states:

"The weight of the structure of all aircraft increases at a greater rate than the load that can be lifted by it. In the case of the airplane, the lift is dependent on the area of the wings, which, in geometrically similar craft, varies as the square of a linear dimension, say as L^2. The weight of the wings, however, varies as L^3. The wings may be considered as beams, usually double-cantilever, with uniformly distributed load. The load per unit of surface does not change with variation of size, which means, that the loading per unit length of beam varies as the chord of the wing, that is, as L. With the length of the beam varying at the same rate as the chord, the bending-moment varies as L^2, and the weight of the beam, therefore, as L^3. Since the weight that a wing can carry varies only as L^2, it follows that a point will ultimately be reached at which the wing will not be able to lift its own weight. This argument applies directly to geometrically similar wings only; and it is often contended that the use of a multiplane structure, or the distribution of the weight along the wing, will enable unfavorable conditions to be escaped indefinitely."

Distributing the weight along the beam merely alters the condition of loading of the beam; instead of being a double cantilever with the load concentrated at the center, the load can be distributed and the beam can possibly approximate to a continuous one. Some benefit may be obtained from this loading, although practical objections, especially in the nature of landing-shocks, render it doubtful. The law, however, still remains: a modified type of beam increasing in weight at a greater rate than the weight it lifts.

The same thing holds for the use of a multiplane structure. The increase in length of the beam may apparently be checked by using more beams of shorter length. In practice, however, it appears that the gain from this source is balanced by a loss in aerodynamic efficiency. The change from monoplane to biplane increases the effective depth of the beam approximately eight times, and reduces the length for similar aspect-ratio to 0.707 of its monoplane value. It barely pays to make this change;

and monoplanes can exist in competition with biplanes. The increase from biplane to triplane merely doubles the effective depth of the beam and reduces the length to 0.815 of its biplane value. This does not pay in normal-size machines but appears to be a cheaper expedient than facing the 3/2 law in craft of the largest sizes now being built.

In a properly equipped airplane ready for regular service, the dead-weight is likely to be between 60 and 63 per cent of the gross load, while in an airship under similar conditions it will probably be 50 per cent. The above percentages for the airship have been estimated on the basis of 100 per cent inflation at sea level. This is an ideal condition; in practice, a safe elevation must be attained immediately after taking the air, and emergency ballast must also be carried. The first condition will probably call for a height of 2,000 feet, involving, with 100 per cent inflation, the dropping of 6 per cent of ballast, or the gas cells can be inflated to 94 per cent fullness only, so that the desired height can be attained without loss of gas. In addition to this deduction of 6 per cent, a certain reserve-buoyancy must be available for emergencies or for trimming the ship preparatory to landing. For this purpose, water ballast is carried, and 5 per cent can be accepted as a fair figure for the amount necessary on the basis of present practice. This 11 per cent must, of course, be deducted from the useful load, which thus, for both types, becomes 40 per cent, or slightly less.

Reserve buoyancy cannot be dispensed with; but sacrificing useful load to obtain it should not always be necessary. By the use of water-recovery apparatus, ballast can be manufactured en route and thus be available at the time that it is usually needed, that is, at the end of the flight. Should an emergency arise early in the course of a flight, it can be taken care of by dropping fuel. "Slip tanks" are provided, in any case, to enable this to be done.

Value of Water Recovery.—Mr. Parker, while assistant physicist at the Naval Academy Factory, Philadelphia, worked out a system of water recovery from exhaust gas that materially reduces the cost of operation of dirigibles inflated with either hydrogen or the more costly helium, the cost of which has been estimated at figures ranging from 20 cents per cubic foot to 5 cents per cubic foot. The former is probably none too high, the latter figure is undoubtedly too optimistic for serious consideration in discussing commercial applications of airships. Mr. Parker also covers this subject in an interesting manner as follows:

"When starting on a flight, an airship is in approximate equilibrium; that is, the lift exerted by the gas within its gas cells approximately equals the total weight of the craft, including the dead-weight of the ship's structure, the ballast, the crew, the useful load and the fuel. As the flight proceeds, this weight becomes gradually less, owing to the consumption of fuel, and the ship becomes light. If no steps were taken to correct it, the first effect would be that the ship would rise, and this would be accompanied by an expansion of the gas within the cells. These cells are normally only partly full but, with increase in altitude, a point is reached where the confined gas expands until it completely fills them. This is known as the "pressure height." Any further expansion would cause in-

creased pressure, which is avoided by providing automatic valves that permit the escape of gas under slight excess pressure. Therefore, with the burning of fuel the ship would rise to her pressure height and gas would gradually escape through the automatic valves. Actually, the ship would be kept at whatever height it was desired to fly her by using the elevators to keep her nose pointed downward, thus balancing the excess lift by negative "dynamic lift," due to the air pressure on the top of her hull that tends to force her down.

On short flights, this expedient is satisfactory; and it is even possible to land a ship considerably light by driving her down in this fashion until the landing party has her in hand. Consequently, on ships making short flights only, this lightness is not a matter of much concern; but, on long flights, conditions are very different. It rapidly becomes impossible to maintain equilibrium by the use of the elevators, and lifting gas has to be valved. With hydrogen, this is not serious, for the gas is cheap and can be replaced when the ship returns to her base. This procedure, however, cannot be adopted with helium because not enough of the gas is available. Even if enough were available, the cost of operating with it on long flights without special measures to conserve it would be excessive. On the Shenandoah, operating at cruising speed, with five engines at 1,200 r.p.m., this cost would be $1,000 per hour assuming that the helium cost 13 cents per cubic foot. This is a very conservative figure at present as it represents merely the cost of producing the gas plus an allowance for transporting the heavy clinders to Lakehurst, N. J., but it neglects all overhead charges. Ultimately, it may be possible to get the cost down to 5 cents per cubic foot; but, even at this figure, it will still be necessary to prevent its waste by old methods of operation."

Preventing Waste of Gas.—Primarily, therefore, the problem is to prevent the wastage of helium. It is often suggested that the gas might be taken out of the cells, compressed and stored on board the ship. While this is possible theoretically, it is altogether impracticable. On a flight of 24 hours with the Shenandoah, the volume that would have to be handled in this fashion would be about 150,000 cubic feet. After compression to say 1,800 pounds per square inch, the gas would have to be stored in cylinders; and, even at this great pressure, the number of cylinders required would be 1,000 and they would weigh 130,000 pounds, a weight as great as the gross lift of the ship. This refers to cylinders of the type used for transporting helium on the ground, but the weight could not be reduced without dangerously lowering the factor of safety. Machinery to compress the gas would also involve very considerable weight, and space would have to be found to store the cylinders. The possibility of reducing the lift by compressing the gas, can, therefore, be dismissed as impracticable.

It is desired not to valve the gas on account of its cost; so, as the ship must be kept in equilibrium, something must be done to keep the weight constant. Therefore, some substance must be collected and stored at the same rate as that at which fuel is consumed in the engines. The most practicable method seems to be to recover water from the exhaust gases of the engines. The necessary water is there, and it has been demonstrated that it can be recovered.

Water in Exhaust Gas.—The point to note is that *for every 100 pounds of gasoline burned, 145 pounds of water is present in the exhaust.* This quantity varies somewhat with weather conditions and also with the composition of the fuel. For gasoline, 135 pounds can be set as the minimum and 150 pounds as a fair maximum; but, with other fuels, the amount of water formed may be greatly different. Thus, with benzol, it is only 70 pounds and, with alcohol, 115 pounds. The water exists first as fog, which cannot conveniently be collected. However, as this fog moves along in the supersaturated atmosphere, the particles coalesce to form water-drops so that, at the exit, probably 75 per cent is available as liquid. The remaining fog can be rendered available as water, by mechanical means. So much for theory. The problem resolves itself into a straightforward cooling proposition which, at first sight, seems not very difficult. The most obvious thing to do appears to be to apply steam-condenser practice, using either a surface or a jet condenser. The conditions, however, differ from those met with in steam condensers in important particulars.

Water Recovery Apparatus.—The apparatus finally evolved by Mr. Parker and his assistants consists of a large number of aluminum tubes fitted into cast-aluminum headers that, in this case, serve to change the direction of the exhaust through approximately 180 degrees every 5 feet. The exhaust gas is first directed from the exhaust-ports into a manifold of normal construction. As the engine is totally enclosed within a car, special means are necessary to cool the manifold, and it is covered with an aluminum casing provided with an intake scoop to direct air through the casing and over the manifold. A cut-out is provided on the manifold, consisting merely of a branch pipe with a plug screwed into its end so that, on the removal of the plug, the engine can be operated while exhausting direct to the atmosphere, and the condenser put out of action. For normal operation, however, the exhaust flows through the manifold proper to a flexible connection to the condenser entrance. This is necessary because the condenser is suspended directly from the hull, and the cars move almost 1 inch from their stationary position when subjected to the thrust of the propellers.

Condenser Details.—At the condenser entrance is a distributor header, an aluminum casting that spreads the exhaust to the 45 tubes of 1-inch diameter which fit into the header. Each of these tubes has a total length of 70 feet, and the gases must traverse their whole length before they reach a terminal header. There they are again collected and passed through a separator that is merely a tank provided with baffles to arrest the fog particles and prevent them from being swept out with the residual gases of the exhaust. The baffles cause the gases to change their direction of flow sharply and, as the fog particles are heavier than the actual gas particles, they tend, due to their inertia, to keep on in a straight line, while the gases sweep around the corner and out of the exit. Drain pipes permit the condensed water to flow into the engine cars, where are located a filter to remove soot and oil, a storage tank and a pump for delivering the water to a distribution line in the hull. This line leads to the ballast bags and, by opening the appropriate valves, the recovered water can be directed to any bag desired.

Temperature of Gases.—The gases enter the manifold at a temperature of about 1,600 degrees fahrenheit; this has fallen to 1,100 degrees fahrenheit by the time the condenser entrance is reached, and to 400 degrees fahrenheit at the end of the first 10 feet. Condensation starts after approximately 23 feet of travel; so, it takes twice as much surface to cool the last 40 degrees as is necessary to cool the first 1,000 degrees. The actual time taken for the process is less than 2 seconds; that is, within 2 seconds of the time the gas leaves the exhaust-port, the water has been removed from it and it has been discharged to the atmosphere. In spite of the high velocity implied by this short period, the back-pressure is less than 1 pound per square inch, which is negligible compared to the mean-effective pressure of more than 120 pounds per square inch exerted by the engine.

The actual recovery obtained with gasoline was 110 per cent; and the apparatus stood up satisfactorily under its full-load test. This recovery of 110 per cent has since been duplicated in actual flight tests. Only three of the five engines of the Shenandoah were so equipped, as it was expected that these, operating at a recovery of 110 per cent, will suffice for flights of up to 18 hour duration, allowance being made for landing the ship light. These three units, together with water-delivery lines, storage tanks, exhaust connections, and other incidental parts, weigh 1,500 pounds. This may seem a serious reduction of the useful load, but it is not necessarily a loss.

Use of Ballast.—Ballast must be carried on an airship for use in possible emergencies in landing the ship. It may not be needed at all, but careful piloting requires that it be available. A fair figure for the amount usually carried is 5 per cent of the gross lift. In support of this it might be mentioned that the R-34, in crossing the Atlantic, carried more than 3 tons, or more than 5 per cent. In that case, if ever, it was imperative to reduce the ballast to the absolute minimum. This figure represents 6,500 pounds for the Shenandoah. Without the water recovery, this must be taken on at the start of the flight; with water recovery it can be manufactured en route so that, instead of reducing the useful load, the installation of water recovery may materially increase it.

Some Advantageous Features of Airships.—One of the greatest risks to aircraft lies in making a landing. If it were necessary to house an airship in its shed at the termination of every flight, and at the same time to maintain a regular schedule, the risk of damage due to its being caught in eddies and gusts would, no doubt, be appreciable; but when the ship need return to its hangar only for overhauling or repair and can, within limits, choose its own time for doing so, making its regular stops at a mooring-mast to maintain a regular schedule without much risk in making connection with the earth should be possible.

The risk of damage arises from direct contact between the moving aircraft and a fixed object, and the resulting damage is dependent primarily upon the momentum with which this contact is effected. In spite of its great mass, an airship can usually approach the ground at a very low velocity. On the other hand, an airplane must make contact at a relatively high-speed and, if anything should go wrong, the consequences are more serious.

In the case of passengers, the risk of injury depends on the velocity of the aircraft at the time of impact. Serious injury may occur if this velocity exceeds about 20 m.p.h. It is obvious that this risk is present in an airplane but is negligible in an airship.

Stays Aloft With Engines Stopped.—Engine stoppage is the direct cause of much of the trouble that aircraft may encounter and may arise from either mechanical breakdown or exhaustion of the fuel supply. In an airplane, either cause will involve a forced-landing, and this is always accompanied by a risk of appreciable magnitude. In an airship, no immediate danger exists; the power plant is split into three or more units, and one-half of them may fail, yet the journey can still be completed in little more than the scheduled time; even though all but one should fail, a base can be reached at reduced speed. Furthermore, the engines are accessible and, except in the case of really serious breakdowns, repairs can usually be made in the air.

Dirigible Can Be Controlled as Free Balloon.—Even exhaustion of the fuel supply does not place an airship in immediate danger, since it can remain in the air and "free balloon" for at least 24 hours. It cannot remain up indefinitely, owing to variations of temperature that require either the discharge of ballast or the valving of gas. The variations that cause trouble are those between the air and the lifting-gas, namely, superheating, which may easily cause an excess lift amounting to 5 per cent of the gross lift of the ship. In an airship, the engines of which have stopped, this would involve a rise to pressure height and a discharge of gas through the automatic valves. When the gas began to cool at a greater rate than the air, ballast would have to be discharged. Enough water is normally carried to enable an airship to remain out 1 night, but whether it could endure a second is doubtful.

In this respect, a prospect of even greater safety in the use of water recovery exists, for, with all the fuel gone, an equivalent weight of water would be available, which should outlast some four or five nights. If an emergency arose, for example, through being blown off the course by a storm near the end of a flight, an airship captain, assured of enough reserve buoyancy to outlast several nights, could conserve his remaining fuel, and free balloon until the storm abated. With services in regular operation, enough bases or masts should be in existence for him to reach one in safety at reduced speed after the abatement of the storm, and he could then refuel and resume his voyage. Whatever the exact measures adopted, the ability to remain in the air without danger for so long a period would give the captain much greater freedom in meeting an emergency.

Depreciation and Cost.—No satisfactory data on depreciation are yet available, nor can they be expected until an appreciable number of aircraft of both types have actually been worn out in service. The most perishable item, the fabric outer-covering, is subject to a similar deterioration in both types. The main structural members, so far as can be seen at present, are in a similar position. In its gas cells the airship possesses a perishable item not shared by the airplane. The life of these is possibly twice that of the outer-covering and one-third that of the hull. So long as gold-beaters' skin is necessary to make the fabric gas-tight, they will, no doubt, be ex-

pensive. However, that a substitute for this material will ultimately be found seems probable.

This disadvantage of the airship should be offset by the greater durability of its engines. In an airplane, the engine is normally called upon to operate for short periods at full power and for fairly long periods at a relatively high output; in an airship, full power is very rarely called for and the usual operating-speeds represent a relatively small load. A given engine could be expected to last longer, therefore, in an airship. At present, airship engines are built heavier, and for this reason are more durable. This advantage, however, is not likely to be permanent, since, with less exacting requirements, to save weight by using engines no heavier than those which are satisfactory in an airplane, where the utmost in reliability is required, would pay.

As the relative cost of airplanes and airships the heavier-than-air is cheaper than the lighter-than-air craft. Airplanes may be purchased as low as $2,000 per ton in the case of lightweight machines, up to $5,000 per ton for ordinary wood and fabric or composite construction and $8,000 per ton for all-metal airplanes in moderate production. Airships will cost from $10,000 per ton for small non-rigid constructions to $20,000 per ton for semi-rigid and rigid types. These figures include the cost of power plants. A factor of moment that demands consideration when comparing cost is that of the gas necessary to fill an airship and this is no inconsiderable item. With helium at 10 cents per cubic foot, it would cost $100,000 to inflate a ship of 1,000,000 cubic feet capacity.

Dirigible Balloon Types—The Blimp.—The "Blimp" type of balloon is a non-rigid form in which the shape of the gas bag is maintained by means of an interior ballonet which may be filled with air either from the slip stream of the propeller or by means of a separate blower outfit driven by an auxiliary power plant of the small air-cooled engine form as used for motorcycle propulsion. The amount of air entering the ballonet can be controlled by the operator and, of course depends entirely upon the condensation or expansion of the gas used inside of the bag as a lifting medium.

A typical "Blimp" used by the navy during the World War is shown at Fig. 12, and this type of aircraft received considerable application for patrolling purposes. It is capable of reasonable speed in the latest types such as shown at Plate 7 which are provided with engines of 100 or more horsepower, and is of especial value in hovering over the sea to locate the presence of submarine boats. The usual construction is to use a special shaped gas bag, or one with a proper streamline form that will provide for minimum air resistance and ordinary airplane type fuselage, with places for two operators, suspended from the bag by means of the usual suspension wires. The semi-rigid type, in which a keel is used to strengthen the structure, which extends from bow to stern as shown in Plate 8 is sometimes erroneously referred to as a Blimp. It is much more rigid than the simple gas bag types but is not as costly to construct nor as strong as the rigid types improved from Zeppelin practice. These are capable of speeds from 35 to 50 miles per hour and are provided with lifting planes and rudders to facilitate control. Where the lifting planes are used it is not always necessary to change the amount of gas in the container or to throw out

ballast to obtain different altitudes. These changes may be obtained by manipulation of the rudders, and as the gas is retained for longer periods it is possible to make longer trips without excessive wastage of gas. This type was extemporized to meet an emergency and at the present date, even the small non-rigid type has been greatly improved. Attention is directed to the illustration at Plate 9 which shows the Goodyear "Pilgrim," a small airship of 50,000 cubic feet capacity. It is 105 feet long and 31.5 feet in diameter.

The Pilgrim, A Goodyear Blimp.—This interesting small dirigible was described by H. T. Kraft, in Aviation and a summary of its characteristics given that should interest the student. The general layout of The Pilgrim deviates considerably from past practice of non-rigid airship design, the principal changes being in the suspension, nose construction, keel construction, and fin design. The ship has some characteristics of a semi-rigid which allow it to be housed in the hangar at zero pressure without serious deformation of the hull and thereby considerably reduces fabric tension and the occasion for high diffusion. The keel is a magnesium girder of triangular section, tapering at the ends and is 21 feet long. The keel weighs but 30 pounds and is laced on the inside of the envelope after the ship is inflated. It is readily removable and full facilities are offered for adjusting any of the suspension cables that radiate to the top of the envelope and there spread out into two longitudinal catenaries. The result is that the ship maintains practically a circular cross section at all times except for a slight indentation at the point of attachment at the top of the envelope. The car is suspended to this keel by a series of wires which are very short and rigid and the difficulty of perfect adjustment of these cables is entirely eliminated.

At the rear of the car there is a steel "wishbone" which fastens to the keel at the center of gravity of the engine. This wishbone acts primarily as a torque arm to relieve the car of torsional reaction of the engine. The engine is mounted to a combination rubber and fabric base which is fastened to the car, eliminating any direct mechanical connection between the power plant and the car. The upper end of the wishbone is also fitted with similar material to dampen the vibration and incorporates a ball and socket joint to allow free articulation at the point of attachment to the keel. A Reed four blade propeller with spinner is used which gives a higher efficiency than the wooden type. The propeller weighs but 32 pounds.

The entire car is constructed of steel tubing of 0.03 inch wall 0.75 inch diameter. The car is covered with 0.02 inch magnesium sheeting with watch case crystal celluloid windows of heavy gage. One section of the car was given a 5,000 pound static load before it failed, which indicates that the car is very light and strong and will withstand severe landing shocks. The interior of the car is upholstered in blue mohair velour with mahogany finished veneer below the window lines. Seats are provided for one pilot, two passengers and a cockpit at the rear for the motor mechanic.

The fuel system consists of a Stewart Vacuum tank which works satisfactorily on a small engine of this horsepower. The engine is a 60 hp. Wright Gale (L-4), three cylinder radial and has a crescent shape exhaust

manifold leading the exhaust down to a muffler which considerably reduces the exhaust noises. The instrument and controls are conveniently located on board ahead of the pilot with throttle and spark control arranged on the left side of the pilot seat. The rudder bar is provided for directional control with the elevator wheel at the right side of the pilot's seat for vertical control.

The envelope has a capacity of 50,000 cubic feet of helium gas and has an aspect ratio of 3.4 to 1. Two valves are provided, one for discharging gas in extreme emergencies and the other for ballonet control. During all general flying conditions there should be no cause for valving helium in view of the great controlability of the ship dynamically. The nose cone construction is a rather radical departure from the usual design. The structure consists of a tube 16 feet long, 3.5 inch in diameter of 0.03 inch wall and has six radiating cables which attach to the interior of the envelope. These cables greatly tend to hold the nose out even at zero pressure. It is of the self energizing type and resembles a bow and arrow construction where the tube represents the arrow. Stability is an item of importance on a small ship of this type and large surfaces well streamlined were decided upon to give the ship excellent maneuvering qualities.

The envelope is 105 feet long and 31 feet 6 inches in diameter. This shape being selected because of less resistance as well as being economical from the standpoint of surface area. The hull has but one ballonet with its center of volume located over the center of disposable load so that there should never be any serious out-of-trim conditions during flight. The ship has a speed of 51 m.p.h. and a fuel consumption of 4.6 gallons per hour. While provisions are made for carrying two passengers and the pilot, the number carried depends upon the desired cruising radius and the desired ceiling. The gasoline tank has a capacity of 32 gallons.

A small mooring mast attachment is on the ship. It consists of a 32 inch diameter aluminum spinning securely bolted to a fabric reinforcement located on the under side of the ship near the nose. This was done for simplicity of attachment and the satisfaction of having a mast that is but 16 feet high which can be easily transported and erected in a few minutes. The release is either controlled from the ground or from the car and the mechanism consists of a doll pin which is withdrawn by a cord and permits the ship to be released at will.

Characteristics

TYPE AD AIRSHIP

HULL

Envelope

Volume (theoretical)	50,068 cu. ft.
Volume (with 5% stretch)	52,570 cu. ft.
Length	105 ft. 6 in.
Diameter of envelope	31 ft. 1 in.
Height of ship	44 ft. 0 in.
Width of ship	40.7 ft.
Fineness ratio	1/3.4
Surface area	881 sq. yd.

Ballonet

Volume	13,750 cu. ft.
Per cent of envelope volume	27.5
Surface area	219.6 sq. yd.
Ceiling of ship (based on bal. vol.)	10,500 ft.

Control and Stabilizing Surfaces

	Area sq. ft.	Act. wt.
Lower vertical fin	98	43 lb.
Upper vertical fin	127	50 lb.
Horizontal fins (2)	238	94.75 lb.
Rudder	54.5	24.75 lb.
Elevators (2)	99	49.10 lb.
Total	616.5	261.60 lb.

CAR

General Dimensions and Characteristics

Length	14 ft. 6 in.
Width	3 ft. 9 in.
Height	5 ft. 9 in.
Structure	Steel tubing
Covering	Magnesium
Seats	4

Power Plant Characteristics

Motor (1)	60 hp. Lawrence
R.p.m @ 60 hp	1850
Propeller	4 blade, Curtiss-Reed dural
Diameter	6 ft 5 in.

MISCELLANEOUS WEIGHTS

Hull

Envelope	619 lb.
Ballonet	155 lb.
Surfaces	262 lb.
Envelope accessories	312 lb.
Total	1348 lb.

Car

Structure	409 lb.
Motor	175 lb.
Propeller	29 lb.
Suspension beam	62 lb.
Total	675 lb.

LIFT AND WEIGHT SUMMARY

Gross lift (helium) @ 56 1-1000 vol. = 52570	2944 lb.
Hull dead weights	1348 lb.
Car dead weights	675 lb.
Useful load	921 lb.
Useful load per cent of total lift	32.4 lb.

DISTRIBUTION OF USEFUL LOAD

Pilot	180 lb.
Passenger	180 lb.

Mechanician	180 lb.
Parachutes (3)	60 lb.
Gasoline and oil	214 lb.
Water ballast	107 lb.
Total	921 lb.

PERFORMANCE DATA	Full power	Half power
Fuel and oil consumption—hp./hr..	0.54 lb.	0.27 lb.
Horsepower	60	30
Fuel and consumption—hr.	32.4 lb.	16.2 lb.
Endurance—hours	6.61	13.22
Speed mi./hr.—estimated	50	39.7
Range—mile	330	525

50% increase in range if gasoline is substituted for water ballast

A Metal-Clad Rigid Airship.—Several years ago, an organization of leading men in the automotive industry formed a development syndicate that had as its primary purpose the development of a rigid airship that would be durable and permanent in construction, fire and weather proof, operative in all kinds of weather, and economical in the use of gas and it was decided that an approximately all metal construction would be necessary to attain these objects. Ralph H. Upson, a practical aeronaut and an authority with wide experience with lighter-than-air craft and one of the pioneer operators of such airships in this country became the Chief Engineer for this group. In a paper read before the Society of Automotive Engineers and published in the S. A. E. Journal the subject of metal-clad airships was discussed in a very thorough manner and a description was given of some of the preliminary steps that had been taken in the design and construction of an airship of about 200,000 cubic feet capacity. It is from this paper by Mr. Upson that the following excerpts have been reprinted, but as must be evident, due to space limitations, only the high spots of this absorbing subject can be touched on.

The first suggestion in the line of a metal airship, of which we have any record, is due to Father Lana in 1670. He proposed a car to be supported by four hollow spheres of very thin copper, from which the air was to be exhausted, thus making them lighter than air. Propulsion was to be by a sail, which was of course a fallacy, but otherwise the scheme was scientifically sound. It was impossible of realization, not through any violation of natural laws, but because no known material of such necessarily thin gauge could stand the outside pressure. With all the improvement in materials in the last three and one-half centuries we are still far from any possibility of a *vacuum* airship. By filling the hull with a light gas, however, and thus replacing the severe compressive stresses with a preponderance of tensile stresses, the *metal* airship becomes thoroughly feasible.

In 1897 an Austrian named Schwartz designed a sheet aluminum airship, the construction of which was actually finished after his death. It was inflated by fabric gas cells and got into the air but it could not be operated due to serious faults in the structure, power plant and controls.

Zeppelin's first metal-framed airship was also a failure but his genius and perseverance won out in the end, and the duralumin framed Zeppelin became the world's standard in airship construction. In a way it had too much success for the good of airship development generally for, although the Zeppelin itself was greatly improved by refinements of design and construction, it naturally discouraged further radical changes, especially during the War. Since the War however the very attractive possibilities of metal construction have proved irresistible.

Already the all-metal airplane is a practical reality, being made from the same duralumin that had previously been developed for the *framing* of airships. Why not use the same material for gas bag covering.

The assumed duralumin plating weighed approximately four times more per square foot than the fabric cover of the usual rigid dirigible covering. Yet the total weight for ships of equal capacity was less! The result was due largely to the manner in which the single metal surface was made to serve a number of different purposes, made possible by the homogeneous character of the structure. Considered as a cover, the metal serves the same purposes as the fabric outer cover but does it more efficiently by eliminating the flapping and moisture absorption so common to fabric. That is, however, only the beginning. In the Metal-clad ship the surface plating also holds the gas and, in combination with the frame members, carries most of the stresses.• The general principle of construction is similar to that of a steamship, in which the frame and plating are neither of them structurally self-sufficient, but each supports and reinforces the other. Thus the present design is far more than and essentially different from a mere metal-*covered* airship.

Requirements of Metal Hull Structures.—The most fundamental and obvious requirement for any metal structure is that it shall not be repeatedly strained beyond the elastic-limit of the material. In effect this necessitates a thoroughly rigid non-deformable structure. If this rigidity were to be maintained throughout the entire hull by structural stiffening alone, the weight would be almost prohibitive. Much therefore depends on building the hull originally of such form and arrangement that the tendency toward distortion is reduced to the minimum. A non-rigid airship is a familiar example of how a natural balance of forces produces a certain rigidity in an otherwise flexible envelope.

Formerly it was thought that an airship had to be long and slim to go through the air easily and have proper stability. Directly or indirectly, this false assumption has been the guiding hand of airship construction for a quarter century. Count Zeppelin based his design on it. The semi-rigid airship was created for it. The non-rigid airship was greatly complicated by it. For the Metal-clad ship, good structural efficiency requires a fairly short and compact hull. The problem was approached by Mr. Upson confident that with the proper curves such a shape could be made efficient. The results are rather surprising. According to the best evidence available, the Navy wind tunnel, the new hull form has a lower resistance for equal volume than any shape hiherto produced. This is for a length-diameter or fineness ratio of only 2.8 to 1.0 compared with 7.2 to 1.0 for the most recent Los Angeles and 8.6 to 1.0 for the Shenandoah.

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Gasoline and oil	214 lb.
Water ballast	107 lb.
Total	921 lb.

PERFORMANCE DATA	Full power	Half power
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50% increase in range if gasoline is substituted for water ballast

A Metal-Clad Rigid Airship.—Several years ago, an organization of leading men in the automotive industry formed a development syndicate that had as its primary purpose the development of a rigid airship that would be durable and permanent in construction, fire and weather proof, operative in all kinds of weather, and economical in the use of gas and it was decided that an approximately all metal construction would be necessary to attain these objects. Ralph H. Upson, a practical aeronaut and an authority with wide experience with lighter-than-air craft and one of the pioneer operators of such airships in this country became the Chief Engineer for this group. In a paper read before the Society of Automotive Engineers and published in the S. A. E. Journal the subject of metal-clad airships was discussed in a very thorough manner and a description was given of some of the preliminary steps that had been taken in the design and construction of an airship of about 200,000 cubic feet capacity. It is from this paper by Mr. Upson that the following excerpts have been reprinted, but as must be evident, due to space limitations, only the high spots of this absorbing subject can be touched on.

The first suggestion in the line of a metal airship, of which we have any record, is due to Father Lana in 1670. He proposed a car to be supported by four hollow spheres of very thin copper, from which the air was to be exhausted, thus making them lighter than air. Propulsion was to be by a sail, which was of course a fallacy, but otherwise the scheme was scientifically sound. It was impossible of realization, not through any violation of natural laws, but because no known material of such necessarily thin gauge could stand the outside pressure. With all the improvement in materials in the last three and one-half centuries we are still far from any possibility of a *vacuum* airship. By filling the hull with a light gas, however, and thus replacing the severe compressive stresses with a preponderance of tensile stresses, the *metal* airship becomes thoroughly feasible.

In 1897 an Austrian named Schwartz designed a sheet aluminum airship, the construction of which was actually finished after his death. It was inflated by fabric gas cells and got into the air but it could not be operated due to serious faults in the structure, power plant and controls.

Zeppelin's first metal-framed airship was also a failure but his genius and perseverance won out in the end, and the duralumin framed Zeppelin became the world's standard in airship construction. In a way it had too much success for the good of airship development generally for, although the Zeppelin itself was greatly improved by refinements of design and construction, it naturally discouraged further radical changes, especially during the War. Since the War however the very attractive possibilities of metal construction have proved irresistible.

Already the all-metal airplane is a practical reality, being made from the same duralumin that had previously been developed for the *framing* of airships. Why not use the same material for gas bag covering.

The assumed duralumin plating weighed approximately four times more per square foot than the fabric cover of the usual rigid dirigible covering. Yet the total weight for ships of equal capacity was less! The result was due largely to the manner in which the single metal surface was made to serve a number of different purposes, made possible by the homogeneous character of the structure. Considered as a cover, the metal serves the same purposes as the fabric outer cover but does it more efficiently by eliminating the flapping and moisture absorption so common to fabric. That is, however, only the beginning. In the Metal-clad ship the surface plating also holds the gas and, in combination with the frame members, carries most of the stresses. The general principle of construction is similar to that of a steamship, in which the frame and plating are neither of them structurally self-sufficient, but each supports and reinforces the other. Thus the present design is far more than and essentially different from a mere metal-*covered* airship.

Requirements of Metal Hull Structures.—The most fundamental and obvious requirement for any metal structure is that it shall not be repeatedly strained beyond the elastic-limit of the material. In effect this necessitates a thoroughly rigid non-deformable structure. If this rigidity were to be maintained throughout the entire hull by structural stiffening alone, the weight would be almost prohibitive. Much therefore depends on building the hull originally of such form and arrangement that the tendency toward distortion is reduced to the minimum. A non-rigid airship is a familiar example of how a natural balance of forces produces a certain rigidity in an otherwise flexible envelope.

Formerly it was thought that an airship had to be long and slim to go through the air easily and have proper stability. Directly or indirectly, this false assumption has been the guiding hand of airship construction for a quarter century. Count Zeppelin based his design on it. The semi-rigid airship was created for it. The non-rigid airship was greatly complicated by it. For the Metal-clad ship, good structural efficiency requires a fairly short and compact hull. The problem was approached by Mr. Upson confident that with the proper curves such a shape could be made efficient. The results are rather surprising. According to the best evidence available, the Navy wind tunnel, the new hull form has a lower resistance for equal volume than any shape hiherto produced. This is for a length-diameter or fineness ratio of only 2.8 to 1.0 compared with 7.2 to 1.0 for the most recent Los Angeles and 8.6 to 1.0 for the Shenandoah.

The improvement in aerodynamic stability is even more striking. With a new fin arrangement totalling 17 per cent *less area* than the Zeppelin type surfaces, for equal volumes, *the stability and control is more than twice as good*, and studies now under way give promise of still better results. This almost revolutionary improvement is largely due to the detail of the fin arrangement in which a greater number of small units, in this case eight, is used, instead of the four that became conventional about 10 years ago. The aerodynamic lift is almost double that of the long, slim hull for equal volumes.

Metal-Clad Hull Construction.—The hull is entirely of metal except for an internal fabric diaphragm separating the ballonet or air-compartment from the gas above. This diaphragm yields with varying proportions of gas and air in the same way as the bottom portion of the gas cells in a conventional rigid airship. In the MC-2 the general design of which is shown in Fig. 13 the ballonet diaphragm will normally be kept flat down against the bottom of the hull, in effect making a metal container of the entire hull throughout the greater part of which the gas is in direct contact with the metal. This highly desirable arrangement naturally depends upon having a reasonably gas-tight surface.

Early encouragement of the possibility of gas-tight seams in duralumin sheet was had by analogy with steel gasometers that are much tighter and more satisfactory than any made of fabric. Many different types of seam were tried without success. However it was apparent that if the same rivet spacing and other dimensions as used in gasometer practice could be reduced in proportion to the thickness of sheet, the *results* should be comparable. The big trouble was the enormous number of tiny rivets, which is about 3,000,000 in the small MC-2, that would be required. This problem has been solved by the successful development of a special riveting machine that automatically puts in more than 5,000 rivets per hour and does it much better than would be possible by hand.

The only thing that was not present in the duralumin seam was the rust that works into the seams of a steel gasometer and plays an important part in making it tight. This property is supplied to the seams independently by a specially prepared seam dope. Tests have averaged less than one-tenth the leakage usually specified for gold-beater-skin fabric. This includes results throughout an extreme range of temperature and after very pronounced vibration, although experiments at the Bureau of Standards indicate practically no vibration from aerodynamic causes. The strength of the standard seam is greater than the yield-point of the material.

Material Used for Metal Hull.—The material itself which is but 0.008 inch gauge and weighs 0.14 pound per square foot is a development of the duralumin manufacturers who have co-operated in a very fine way to render their product available in the form needed. The art of rolling a very long and wide fine-gage duralumin sheet that is unusually flat for the tempered condition and with the gauge closely controlled is a peculiarly American work of the last 3 years and beyond anything that has been done in Germany, England or France. It is interesting to note that the fabric ordinarily used for making a non-rigid hull is 0.021 inch thick and weighs 0.11 pound per square foot. Duralumin, although much less corrosive than

steel, still needs a protective coating for the best results; and an extremely light and efficient preparation has been found for the purpose. The patterning of the surface follows the same general principles as with fabric, but special equipment had to be devised to take care of the greater accuracy required. The internal frame-members are simple in form but have involved practical difficulties of shaping to the exact curve and angle.

Mr. Upson stated that hydrogen would be used for inflating the metal-clad on account of its availability, cheapness, lifting qualities, and the fact that it can be used for reserve fuel, which will reduce the weight of water ballast recovery apparatus. That hydrogen in a metal hull is at least as safe as gasoline in a metal tank should be fairly obvious. If helium is desired, however, it can be used to better advantage than in a fabric airship because of the almost negligible leakage through the metal hull, and the higher gas purity that can be maintained. Even with helium, it is a great asset that the surface of the ship itself is fireproof.

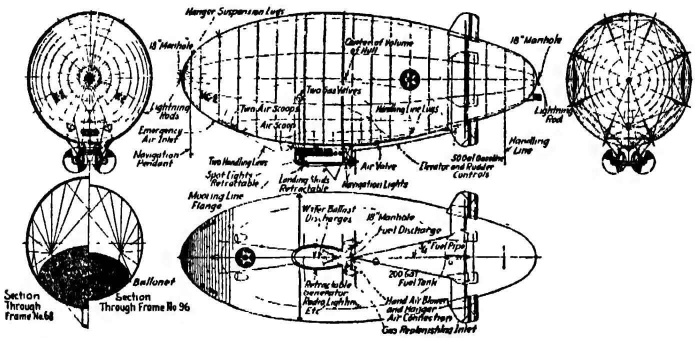


Fig. 13.—Diagrams Showing Main Details of Metal-Clad Airship of 200.000 Cubic Feet Capacity in which Sheet Duralumin Replaces Rubberized Fabric as Material for the Gas Container.

Several questions have been raised as to the effect of the high thermal and electrical conductivities of the hull, the common idea being apparently that these would be unfavorable operating-factors. Actually they are just the reverse. The metal surface heats-up considerably in the sun, when not in motion, but this is usually an advantage at the start. In operation, thermal disturbances in the lift are eliminated by keeping the gas at the same temperature as the outside air. Indications are that the highly conductant metal surface tends to approach this ideal when in rapid motion through the air, most of the radiant heat being carried off again as fast as received.

In respect to electric conductivity all authorities seem to be agreed that the metal airship will be absolutely static proof and almost, if not entirely, lightning proof. The only danger conceivable from lightning is that a sudden charge might cause a momentary current so severe as to produce local fusion of the material. This has been observed in the case of wires where the current is restricted to one dimensional flow, but for a flat surface it seems at least reasonable to suppose that any charge would spread out over enough area to prevent melting through at any one spot.

Notable Airship Flights.—The flight of the airship Norge from King's Bay, over the North Pole and to Teller, Alaska, in May, 1926 was an outstanding achievement. During the War, a Zeppelin airship, the L59 flew from Jamboli, Bulgaria to German East Africa and return. The airship was in the air for 100 hours, travelled about 4,500 miles and upon its return there was enough fuel for 50 hours more of travel. The airship "Bodensee" built for passenger service in Germany after the war made regular trips between Berlin and Friedrichshafen and in 98 days carried 2,380 passengers about 32,300 miles together with 18,000 pounds of baggage and express matter. The English airship the R34 flew from East Fortune, England across the ocean to Mineola, L. I., New York and return in July, 1919. It was in the air 108 hours and covered 3,600 miles coming over and 3,450 miles in 75 hours, going back.

The only flight of a non-rigid airship of any great importance was that of the Navy's C-5, which flew from Montauk, Long Island, to St. Johns, Newfoundland, in 1919. The ship covered a distance of about 1,200 miles in 25½ hours. The West Coast trip of the airship Shenandoah was one of the greatest achievements of any lighter-than-air craft ever built. On this flight, the Shenandoah traveled 9,317 miles and was away from her hangar 19 days and 19 hours, crossing mountain ranges, deserts, plains and sea, from the Atlantic to the Pacific, and from Canada to Mexico, experiencing all varieties of weather and climate, much of which was adverse. This cruise was made without the availability of a shed or hangar, and newly erected mooring masts were depended upon to provide facilities for fueling, gassing, provisioning and repair. The next flight of interest was that of the Los Angeles which covered 5,100 miles in October, 1924, in 81 hours in a flight from Friedrichshafen, Germany to Lakehurst. The Atlantic Ocean, in this flight, was crossed in 64 hours. This ship, in February of 1925, also made a voyage to Bermuda and back, mooring at the U.S.S. Patoka, the only ship afloat with a mooring mast. It has made frequent flights, accompanying the Navy battleships in maneuvers both in Northern and Southern waters, and it has been a familiar sight to residents of the Eastern and New England States.

Airship Control.—In discussing the subject of control of dirigibles one must distinguish between static control and dynamic control. The former means of ascending and descending is just as in a free balloon, by valving gas to descend and throwing off or discarding ballast to lighten the ship in ascending. When expensive gases are used for sustentation it will be evident that static control will be resorted to only in emergencies as valving gas means a loss of valuable material, especially when helium is used. Dynamic control is by surfaces at the stern that act similar to the same type of control members used on airplanes. As long as the airship is moving fast enough to have steerage way, the controls are effective, reaching their maximum effectiveness at the highest dirigible speeds. Horizontal surfaces that are fixed act as stabilizers and the usual vertical fins or stabilizers are likewise provided. When the airship has steerage way, moving the vertical rudder will steer the ship in a horizontal direction and operating the elevators will cause the ship to nose up or down as the case may be depending on the direction and degree of inclination of the eleva-

tors. The point about which the airship swings is the center of gravity and in most airships this is very close to the center of buoyancy. Owing to the large size of an airship, its movements, when under dynamic control are slow and deliberate and the control is much more dependent upon the wind and the direction from which it comes than is the case with the smaller and faster moving airplanes. The same principles that obtain in steering an airplane apply to dirigibles, which has no need for ailerons as the airplane has, because such a large vessel is not banked in making turns, this being unnecessary because of the method of sustentation by static means, which is independent of the speed at which the hull moves. The buoyancy of the gas resists the attraction of gravity, not an air reaction

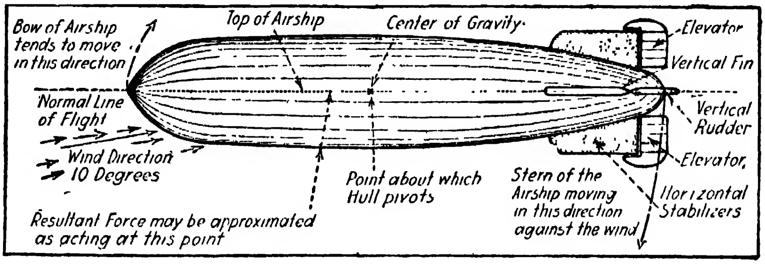


Fig. 13A.—Diagram Showing Influence of Side Wind Acting on Nose of a Moored Airship.

under supporting planes. When an airship is moored, however, it should be so attached that it will always head into the wind. A wind hitting the nose of an airship even at a slight angle will tend to swing it around, as clearly shown at Fig. 13A; because the resultant force, even though it is relatively small acts against the large exposed area forward of the center of gravity and the area of the vertical fins is not sufficient to counteract it. This must be resisted by the vertical rudder.

Safety of Rigid Airships.—The dangers that the rigid aircraft principally face are fire, weather, construction mistakes and operating mistakes. The fire hazard can be dismissed at the outset. With well-built airships skillfully operated, the danger of fire is small even if inflated with hydrogen. In a helium ship the risk is practically non-existent. Only a few ships have been lost due to mistakes in construction and these mistakes apparently had to happen once as part of the price to be paid for progress. Operating mistakes have been made and because the consequences have been spectacular they have attracted more attention than all the safe flights that have been made.

But commercial airships have totaled some 5,000 hours in the air, flown 175,000 miles, and carried 40,000 passengers without accident—not to mention the vast flying experience of the military ships. The only prevention against recurrence of accidents due to errors in judgment is thorough and complete training of flying crews and ground crews. An airship has a high degree of stability and safety but it must be operated by men fully acquainted with its characteristics and able to adjust their plans thereto. Now as to the various weather phenomena and their influence on rigid air-

ships as outlined by the engineers of the Goodyear Tire and Rubber Company, Akron, Ohio, who, through their subsidiary the Goodyear-Zeppelin Company, control these patents and processes in the United States.

Rain—The cover of the airship is doped to resist water. Rain is only an inconvenience. Snow—On account of the speed of the ship the snow blows off in flight, except wet snow, in which case the commander will slightly change the altitude of the ship and get into drier air. If the snow falls on the ship at the mast it may be necessary to take off and make a short flight to give the wind a chance to clear it off. Hail—Even the largest hailstones do no damage to the airship, as the outer cover has the same strength as metal of the same thickness and is, of course, more resilient.

Cold—The lift of the ship is better in cold weather than in warm and permits extra provisions being made for the comfort of the crew if necessary. Heat—This has some effect on the buoyancy since the air is lighter and more rarified but offers no special operating difficulties. Airships have flown successfully in the tropics.

Wind—The effect of wind on the airship is not entirely understood because of the comparison of its effect on anchored objects like trees or houses or those moving slowly like ocean vessels. The airship, however, is moving with the air currents. If a ship were to fly in a 60-mile gale with all its engines shut off like a free balloon, the passengers would be conscious of no sense of motion at all. If they stuck a hand out of the window there would be no rush of air past it. The airship during such a gale is not subject to anything like the stresses tugging at a house which cannot move, or a ship at sea whose response to the wind's movements is impeded by the water. If the wind is moving in the same direction as the ship it merely increases its speed to that extent. If flying against the wind its forward speed is retarded. An 80-mile-an-hour airship bucking a 30-mile wind would be actually making only 50 m.p.h. The airship pilot figures shrewdly to take advantage of winds and hunts for storms rather than avoiding them. Storms generally move across the country in regular cycles at comparatively low forward speeds and with a turning movement, counterclockwise, that is in the opposite direction of the hands of the clock. The airship commander, wishing to utilize the storm, maneuvers to get it at his back so it will carry him in the direction sought. He actually utilizes the storm to save fuel.

Operation of airships over land, however, has one element which exists only in a smaller degree over the ocean—that is local storms, gusts and turbulences which result from the uneven character of the ground, hills and valleys, and from the unequal heating of the earth's surface. When the air is warmer at one point than at another the cold air rushes in forcing the warm air up. An unequal heating over a considerable area brings about uneven winds, thunderstorms and the great loops of rising air known as line squalls. An airship commander meeting a line squall makes the ship heavy, keeping it low down. If the front is too wide for him to fly around he will watch for an opening where the storm is not fully developed and break through. The presence of such openings may be recognized by the cloud formation by day and the absence of lightning by night.

Lightning—The metal framework of the rigid airships forms a "Faraday Cage" where lightning if it hits the airship is distributed and escapes harmlessly through the engine exhaust and at other safe points. Rigid airships have been struck by lightning many times, even those filled with hydrogen. If a commander keeps his ship below the "pressure height" so that no hydrogen is being forced out through the valves he can get through without difficulty. With helium, of course, the lightning danger doesn't exist.

Fog—The airship has an advantage here over the airplane. Whereas a landing in the fog is highly hazardous to an airplane, the airship can simply throttle down its speed and descend vertically, feeling its way to the mooring mast or the hangar. Fogs are usually not accompanied by high winds so this maneuver is not difficult. Tornado—This is the one phenomenon about which complete meteorological data does not exist, but a tornado is only a twister or a whirling movement, on a larger scale. Since the area of the tornado is usually quite limited and its forward speed not great the airship should have no difficulty avoiding them. The summary completes the various weather phenomena which the airship must encounter. There are no other phenomena not known to science.

Since the weather offers the chief difficulties for the airship the obvious defense here is in exact and definite meteorological reports and a complete training of officers and crews. Another highly important addition to safety in airship operation is the mooring mast. The airship in flight is highly responsive to its rudders. On the ground, with engines shut off, it is "walked into the hangar" by a ground crew. Mechanical devices now being perfected largely increase the ease of handling on the ground, even if the wind is gusty and changeable, or there is a light cross hangar wind blowing. As the mooring mast is equipped with fuel, water and gas lines, the ship may remain there for days or weeks.

Terms Relating to Aerostats

Principal Parts

ballonet—A compartment of variable volume constructed of fabric, or partitioned off, within the interior of a balloon or airship. It is usually partially inflated with air, under the control of valves, from a blower or from an air scoop. By the blowing in or letting out of air, it serves to compensate for changes of volume in the gas contained in the envelope and to maintain the gas pressure, thus preventing deformation or structural failure. By means of two or more ballonets, often used in non-rigid airships, the trim can also be controlled. The ballonet should not be confused with gas cell. (Plate 7.)

ballonet diaphragm—The fabric partition between the gas and air compartments of the envelope of a non-rigid or semi-rigid airship or kite balloon.

basket—The structure suspended beneath a balloon for carrying passengers, ballast, etc. It is usually used on a free or kite balloon. (Plate 5.)

bow-cap—(1) A cap of metal or fabric used to reinforce the extreme forward ends of the bow stiffeners of a non-rigid or semi-rigid airship. (Plates 7 and 8.)

(2) The conical or cap-shaped structure at the extreme bow of a rigid airship to which the longitudinal girders are attached and which supports the bow mooring spindle. (Plate 6.)

bow-stiffener—A rigid member attached to the bow of a non-rigid or semi-rigid envelope to reinforce it against the pressure caused by the motion of the airship. Sometimes called "nose stiffener" or "nose batten." (Plates 7 and 8.)

car—That portion of an airship which is intended to carry power unit or units, personnel, cargo or equipment. It may be suspended from the buoyant portion or it may be built close up against it. It is not to be applied to parts of the keel of a rigid or semi-rigid airship which have been fitted for the purposes mentioned. (Plates 6, 7 and 8.)

control car—The car of an airship in which controls are centralized and from which it is operated.

control compartment—A compartment in the control car of an airship from which all controls are operated. It may be compared to the pilot house of a ship.

envelope—The outer-covering of an aerostat, usually of fabric. It may or may not be also the gas container. It may be divided by diaphragms into separate gas compartments or cells, and it may also contain internal air cells or ballonets.

gas cell—One of the gas-containing units fitted in a rigid airship. Sometimes called "gas bag." (Plate 6.)

gore—The portion of the envelope of a balloon or airship included between two adjacent meridian seams.

hull—The main structure of a rigid airship, consisting of a covered elongated framework which incloses the gas cells and supports the cars and equipment. May also be applied to the complete buoyant unit of any aerostat. In this latter sense sometimes called "gas bag."

intermediate longitudinal—An intermediate longitudinal strength member, of a rigid airship, which lies between two adjacent main longitudinals and is generally of lighter weight and/or smaller dimensions than the main longitudinals. (Plate 6.)

intermediate transverse—An open unbraced transverse frame of a rigid airship which lies between two main or braced transverse frames. (Plate 6.)

keel—The assembly of members at the bottom of the hull of a semi-rigid or rigid airship which provides special strength to resist hogging and sagging and also serves to distribute the effect of concentrated loads along the hull. It may be a simple Gall's chain, as in some semi-rigids, or a very extensive structure inclosing the corridor, as in most rigids. (Plate 6 and 8.)

lobe—An air or gas inflated bag fitted at the stern of a kite balloon and acting as a fin or stabilizer to give it aerodynamic stability. (Plate 5.)

main longitudinal—A main longitudinal strength member, of a rigid airship, which connects the various transverse frames. (Plate 6.)

main transverse—A main transverse strengthening frame of a rigid airship provided with wire or girder bracing and spaced at regular intervals throughout the length of the airship. (Plate 6.)

observation platform—A platform or small deck fitted on the top of an airship and used as a post for a lookout and defense, or as a place from which to make observations used in navigating the airship. (Plate 6.)

outer cover—The outside covering of a hull of a rigid airship, usually of some kind of fabric. Sometimes called the "envelope."

sighting pendant—A vertical wire on center line and forward of the control car of an airship, used as a mark in steering, to assist in determining wind direction.

stern framing—All framework, aft of the cruciform girder, necessary to complete the shape and contour of a rigid airship.

wing car—A car suspended off the center line of an airship. It is also called "side car." (Plate 6.)

wire:

antiflutter—A wire in the plane of the outer cover for locally reinforcing the outer cover in that part of the airship and reducing fluttering in flight due to air pressure or propeller wash. Also called "outer cover support wires."

chord—A wire joining the vertices of the polygonal frame of the main transverse frame.

diametral—A chord wire which passes through or near the center of the main transverse frame. It is usually attached to the axial fitting.

fairing—A wire provided as a point of attachment for the outer cover to maintain the contour lines of the envelope of an airship.

main shear—A diagonal wire taking up main shear loads in the structure of a rigid airship.

netting—Diagonal and/or circumferential wire netting fitted between the longitudinals over the entire hull of a rigid airship to transmit the lift of the gas cells to the structure. Sometimes called "gas pressure wires." (Plate 6.)

radial—A wire which extends from an axial fitting at the center of the transverse frame of a rigid airship to a joint of the frame.

secondary shear—Additional reinforcing shear wire.

Detailed Parts and Fittings

air duct—A tube, usually of fabric, supplying air for filling or for maintaining pressure in air-filled parts of an aerostat.

(a) The duct joining the vertical and lateral lobes of a kite balloon. sometimes called "interconnecting sleeve" or "trousers" (British).

(b) The duct leading from the air scoop or blower of a non-rigid or semi-rigid airship to the ballonet or ballonets.

air scoop—A projecting scoop which uses the wind or slip stream to maintain air pressure in the interior of the ballonet of an aerostat. A similar device is sometimes used on airplanes to produce ventilation. (Plate 7.)

appendix—The tube, usually located at the bottom of a balloon, primarily used for inflation and deflation. In the case of a free balloon it may also serve as an automatic discharge opening. Originally applied to free balloons only. Should be restricted to the various types of balloons and not applied to airships.

appendix manhole—An appendix of large diameter and usually rather short. It is used more for access than for inflation or deflation. (Plate 5.)

automatic valve—A spring-loaded relief valve fitted to the envelope, ballonet, or gas cell of an aerostat and set to open at a predetermined pressure for the purpose of preventing excessive internal pressure. (Plates 6 and 8.)

Also applied to a type of valve used on some aerostats which opens at a predetermined contained volume or hull dimension.

axial cable—The axial member (usually steel wire cable) sometimes fitted in a rigid airship. It is attached to the central fitting of the radial or diametral wires of each main transverse and to the hull structure at bow and stern. Its purpose is to provide support for the radial or diametral wires in an axial direction and thus assist them to sustain the load which might be caused by unequal pressure in adjacent cells or by the airship being pitched to a large angle.

axial cone—The cone-shaped fabric fitting in the end of a gas cell of a rigid airship, which provides a gas-tight connection of the cell to the axial cable and yet permits the cell some degree of freedom in its movements. A special form of conical sleeve. (Plate 6.)

band:

mooring—A band of tape or webbing over the top of a kite balloon to which the mooring ropes are attached. It forms part of a mooring harness. (Plate 5.)

suspension—A horizontal fabric band securely fastened to the envelope of a balloon or airship and to which are attached the main suspensions of the basket or car, or the captive cable of a kite balloon. (Plate 5.)

trajectory—A band of webbing carried in a special curve over the surface of the envelope of an airship to distribute the stresses due to the suspension of the car.

batonet—A special form of toggle, usually quite slender and truly cylindrical except for the groove, and used to attach the rigging of a balloon or airship to a fabric loop or suspension band on the envelope.

box girder—Any girder of rectangular section. Frequently used to refer to the rectangular, longitudinal members in the keel of a rigid airship from which fuel tanks and gas bags are suspended.

bridle—A sling of cordage or wire which has its ends fixed at two different points, to the bight of which a single line may be attached, either movably or fixed, thus distributing the pull of the single line to two points or more in the case of a multiple bridle. This term is also used to refer to a towing or mooring line having two legs and intended to reduce yawing when towing or mooring.

bullseye—A circular thimble.

catenary—A line or length of cordage which is secured to or in a piece of fabric in the form of a catenary curve or a series of such curves. (Plate 8.)

chafing patch—A patch of fabric secured to the envelope of an aerostat to protect it from abrasion.

channel patch—A channel-shaped fabric-fitting secured to the envelope of an aerostat to allow a rod or spar to be laced to the envelope.

climbing shaft—An access shaft fitted with a ladder and leading from the bottom to the top of an airship hull. This may be fitted to an airship of any type.

concentration ring:

airship—A ring to which several rigging lines are led from the envelope and from which one or more lines also lead to the car.

free balloon—A ring to which are attached the ropes suspending the basket and to which the net is also secured. Sometimes called "load ring."

conical sleeve—A cone-shaped fabric, fitting in a bag or cell through which a line passes. It provides a gas-tight connection of the bag or cell to the line and yet permits both some degree of freedom to move.

control lines—Lines of wire and/or stranded cable leading from the control car or compartment to the various parts of an airship, and operating either through mechanisms or directly, the rudders, valves, etc., which control the speed, altitude, etc., of the airship.

cradle:

building—A support provided for the frame of a rigid airship or the keel of a semi-rigid airship during construction.

docking—A support for the car of an airship while it is being inflated in the shed. Mostly used with rigid airships.

crow's-foot—A system of diverging short ropes for distributing the pull of a single rope.

An arrangement in which the strands of a cord are opened out so that they can be effectively cemented to a fabric surface.

cruciform girder—The structure, consisting of vertical and horizontal transverse girders, which is fitted at the stern of a rigid airship for the purpose of supporting the inboard ends of the sternposts of the fins or the rudderposts. It may be integral with the sternposts which form the after ends of the fins.

drag rope—A long rope which can be hung overboard from a balloon so as to act as a brake and a variable ballast in making a landing. Same as "trail ropes" or "guide rope." On airships a similar rope, or ropes, is used as a haul-down or mooring line by the landing crew. It is usually larger and longer than the regular handling lines. Sometimes called "grab line."

drip flap—A strip of fabric attached by one edge to the envelope of an aerostat so that rain runs off its free edge instead of dripping into the basket or car. It also assist in keeping the suspension ropes dry and nonconducting. Also called "drip band" and "drip strip."

D-ring—A ring having (as the name implies) the shape of a capital D, to which rope suspensions are attached.

field-handling frame—A portable frame which may be attached to an airship when it is on the ground and which is intended to afford a grasp to more men than could get on the handling rails of the cars. These frames are rarely carried when in flight.

finger patch—A special form of patch having extensions or "fingers" extending out from the central portion. The "fingers" may be of tape, frayed-out rope, or fabric. Their function is to distribute the load more widely to the fabric of the envelope or gas cells.

fin carrier—A frame to which the inboard edge of the fin of a non-rigid or semi-rigid airship is attached, so as to prevent the edge of the fin from sinking into the envelope.

fin girder—A girder of a rigid airship which goes to make up the fin.

gas shaft—A duct or shaft leading from the bottom of the gas cells to the outer cover of an airship. It affords a clear passage for the escape of gases which have accumulated in the gangway or corridor, or which are discharged from the valves at the bottom of the cells. It usually consists of light wooden hoops or frames spaced at intervals on cords or wires, and is covered by a netting. It prevents the gas cells from closing hard against one another and thus keeps the passage open. Sometimes called "gas trunk," "exhaust-gas shaft," or "trunk."

In view of the possibility of confusion with parts of an engine-exhaust system, it is believed that "gas shaft" or "trunk" is to be preferred.

gas-shaft hood—A hood or cowl, located on the outer cover of a rigid airship at the outer end of a gas shaft. It is usually made of light wood and fabric and is faced to facilitate the escape of gas. Sometimes called "exhaust-gas hood."

In view of the possibility of confusion with the parts of an engine exhaust system, it is believed that "gas-shaft hood" is to be preferred.

gland—A short tube fitted to an envelope or gas bag in such a manner that a rope or line may slide through without leakage of gas or air.

grommet—A small ring of chord.

handling line—A line attached along the side of an airship for use in maneuvering near and on the ground. Sometimes called "grab line."

inflation manifold—A metal or fabric connection with numerous inlets which permit the passage of gas at the same time from a number of sources (either cylinders or gas holders) to the main inflation tube.

inflation sleeve (or filling sleeve)—A tubular fabric attachment to an envelope or gas bag, serving as a lead for the inflation tube.

inflation tube—A fabric tube leading from the inflation manifold or source of supply to the inflation sleeve of the gas cell or envelope.

jackstay—A longitudinal rigging provided to maintain the correct distance between various parts or fittings on an aerostat.

main mooring line—The line dropped from the bow of an airship to be coupled to the mast main mooring line. (Plate 6.)

maneuvering valve—A manually operated valve fitted to the envelope, ballonet, or gas cell of an aerostat for the purpose of releasing gas or air from within the envelope or gas cell when desired.

maneuvering-valve hood—A hood, or cowl, located on the outer cover of a rigid airship just over a maneuvering valve. It is usually made of light wood or fabric and is faced to facilitate the escape of gas.

manometer-tube gland—A gland fitted to the envelope of an aerostat to form a gas-tight connection for the tube leading to the manometer in the car. Same as "pressure-tube gland."

mooring cone—The grooved conical member at the extreme bow of an airship which engages with a hollow cone at the top of the mooring mast and provides the coupling between the airship and the mooring mast. (Plate 6.)

mooring-cone outrigger—The member, usually tubular, which supports the mooring cone at the bow of the airship. Sometimes referred to as "mooring spindle." (Plate 6.)

mooring harness—A system of webbing bands, fitted over the top of the envelope of a balloon, to which are attached the mooring ropes. Usually found only in kite balloons or observation balloons. (Plate 5.)

mooring line—A line attached near the bow of an airship for securing it to the ground or to a mooring mast.

mooring ring—A metallic ring suspended from one of the forward frames of a rigid airship by wire lines and used for mooring. The vertex of a "three-point mooring" is attached to this ring.

mooring rope—A line attached to a balloon or airship for use in securing it to the ground. It may serve the purpose of a "handling line," or vice versa.

net:

free-balloon—A rigging made of ropes and twine shaped to the upper surface of the envelope, which supports the weight of the basket, etc., and distributes the load over the entire upper surface of the envelope.

gas-cell (rigid airship)—A netting of cord of small mesh which is intended to assist the fabric of the gas cells in transmitting gas force to a wire netting of coarser mesh and to the longitudinals, both being fitted between the longitudinals. It may be compared to the net of a free balloon. Sometimes called "gas-cell netting" or "cord netting." (Plate 6.)

inflation—A rectangular net of cordage used to restrain the envelope of the kite balloon or airship during inflation. Also applied to a free-balloon net designed to be removed after inflation.

patch—A strengthened or reinforced flap of fabric of special shape and construction, which is cemented to the envelope or gas cell. It usually forms an anchor by which some portion of the structure may be attached to the envelope or to which the positioning lines, controlling the gas cell, may be attached to the cell.

pressure flap—A flap valve fitted in the outer cover or envelope of a rigid airship and arranged to permit the rapid flow of air in and out, particularly inward. The purpose is to facilitate the rapid equalization of the pressure of the air within the envelope with that of the surrounding air.

pressure-relief vent—A small opening in the covering of the fin of an airship intended to facilitate the equalization of the pressure of the air within the fin with that of the outside air. It also provides an outlet for any gas that may collect in the fin.

pressure tube—A tube fitted to an envelope of a gas bag, to which a pressure gauge may be attached.

propeller reinforcing girder—A light additional member fitted in the structure of a rigid airship to reinforce those areas of the outer cover which are affected by the propeller wash.

quadrant—The operating lever, made on the arc of a circle of a control surface of an airship, e. g., rudder quadrant, elevator quadrant.

rip cord—The rope running from the rip panel to the car or basket, the pulling of which tears off or rips the rip panel and causes immediate deflation.

rip panel—A strip of fabric inserted or fitted in the upper part of the envelope of a balloon or semi-rigid or non-rigid airship which is torn or ripped open when immediate deflation is desired. (Plate 5.)

rudder (airship)—A hinged or pivoted surface, usually attached to a fin at the after end of an airship. When operated by the pilot it produces a yawing moment and gives directional control in the plane at right angles to the axis about which it is hinged or pivoted. (Plates 6, 7 and 8.)

safety loop—A loop formed in a rip cord and attached to a securing patch by a breakable cord or a spring clip. It may be formed either inside the envelope and close to the rip panel, or outside the envelope near the gland by which the rip cord passes through the envelope. Before the rip panel can be "pulled" the breakable cord must be broken or the clip opened. Accidental "pulling" is thus made unlikely, as the weight of the cord is easily carried by the breakable cord or spring clip.

sandbag line—A rope extending along the line of suspension ropes or bridles of a kite balloon to which are hooked the sandbags used in mooring the balloon. The purpose is to prevent wear on the suspension cordage.

sandbag loop—A system of cordage loops on the envelope of a balloon for suspending sandbags. See also SANDBAG LINE.

sea anchor—An open fabric bag carried on an aircraft and arranged to offer considerable resistance when towed mouth first through the water. Tripping or collapsing devices may be incorporated in it. Also called "drogue."

supply tube—An elongated appendix or inflation sleeve, fitted on a kite balloon, which is brought down to the basket and fitted with a quick-connection coupling. This coupling can be attached to a similar piece on the deck of the airship and gas may be sent into the balloon shortly after it has reached the deck. A similar tube is sometimes used with airships where constant pressure nurse balloons are used. This is rare in the United States. Also called "nursing tube."

suspension bar—A bar to which the supporting ropes of the basket of a balloon are secured. It is also fitted with ropes and toggles for attaching to the basket suspensions from the balloon. Also called "trapeze bar." (Plate 5.)

suspension line—A line either of cordage or metal which supports the weight attached to the envelope of a balloon or airship.

suspension patch—A patch, secured to the envelope or to a gas cell of an aerostat, to which a suspension line may be attached.

thimble—A grooved ring of circular, pear-, or heart-shaped form, generally of metal, which is inserted in the eye of a rope or wire to prevent chafing or deformation of the eye.

toggle—A short crossbar of wood or metal which is fitted at the end of a rope. The rope passes around the mid-length of the bar in a shouldered groove. By slipping it through an eye in the end of another rope, the two lengths of rope can be quickly connected or disconnected.

topping up—The operation of filling up with gas an already partially full aerostat. Also applied to a similar operation with fuel tanks. Incorrectly called "nursing."

valve hood—The appliance, having the form of a hood or parasol which protects the valve of an airship or balloon against rain. Also called "valve cover" or "bonnet."

valve petticoat—A special sleeve between valve and gas container making it possible to tie off the sleeve and change valves without loss of gas.

valve seal—A fabric cover used to seal the automatic valves of a rigid airship when docked in the shed. Jam pot cover (British).

V-wires—The lower lines of the winch suspension of the kite balloon. They meet at the junction piece and form V's; hence the name. (Plate 5.)

walkway girder—The girder forming the support of a walkway through the keel or in other localities in a rigid or semi-rigid airship. (Plate 6.)

winch suspension—The rigging by means of which the lift and drag of a kite balloon is transmitted from the envelope to the towing or traction cable. (Plate 5.)

yaw line—A line dropped from the bow of an airship when mooring to the mast to act as a steadying line to prevent yawing and overriding the mast. Also called "bow-steadying line" or "yaw guy." ("Side guy wire," British.)

Miscellaneous Terms

aerodynamic volume—The volume of the form which must be driven through the air. Same as AIR VOLUME.

air volume—The volume of air displaced by the body formed by the outer cover or envelope of an airship. It is this volume which enters into aerodynamic computations. See AERODYNAMIC VOLUME.

air-volume displacement (or aerodynamic-volume displacement)—The weight of a mass of air equal to the aerodynamic volume of the airship in N. A. C. A. standard atmopshere at sea level.

buoyancy—The upward air force on an aerostat which is derived from aerostatic conditions. It is equal to the weight of the air displaced.

capacity—The volume of the gas-containing portion of an aerostat.

center of buoyancy—The center of gravity of the volume of the contained gas.

dischargeable weight (consumable weight)—All weights which can be consumed or discharged and still leave the airship in safe operating condition with a specified reserve of fuel, oil, water ballast and provisions, and her normal crew.

displacement—The mass of air displaced by the gas used for inflation. It may be expressed as a weight of volume. In the latter case it is usually called "volume."

disposable weight—All weights other than fixed weights, including dischargeable weights contrasted with fixed weights, q. v.

fixed weight—The weight of the hull machinery and all equipment and parts which are fixed in position and nonconsumable. All constant and nonconsumable weights which an airship would carry under all conditions of service (British). Liquids in cooling systems of engines are included.

gas volume—The volume of the contained gas. See CAPACITY.

gross lift—The lift obtained from a volume of buoyant gas equal to the nominal gas capacity of the aircraft. Obtained by multiplying the nominal gas capacity by the lift per unit volume of the gas used for inflation.

lift (of a gas)—The difference of density of air and the gas. Both are supposed to be under the same conditions of pressure, temperature, etc.

manometer pressure—The excess of pressure inside the envelope of an aerostat over the atmospheric pressure at a standard reference point. The point of reference for the excess of pressure is usually the bottom of the envelope or gas cell for airships and the level of the basket for kite balloons.

nominal gas capacity—The volume of the envelope of gas cells of an aerostat under certain conditions of pressure and inflation which have been defined. It is rarely the same as the true full volume. This is usually very difficult to determine accurately, especially in the case of rigid airships. Sometimes called "volume."

permeability—The measure of the rate of diffusion of gas through intact balloon fabric; usually expressed in liters of hydrogen per square meter of fabric per 24 hours, under standard conditions of pressure and temperature.

pressure height—The altitude at which the gas cells of a rigid airship are full, or the gas bag of a non-rigid airship is completely full of gas.

purity (of gas)—The ratio of the pressure of the hydrogen (or other aerostatic gas) in the container to the total pressure due to all the contained gases.

static ceiling—The altitude in standard atmosphere, at which an aerostat is in static equilibrium after removal of all discharged weights.

volume—The volume of the air displaced by the gas used for inflation.

useful lift—the lift available for carrying fuel, and oil, passengers, cargo, food, and drinking water, guns, ammunition, and bombs. Usually determined by deducting from the gross lift all fixed weights; certain allowances of ballast, fuel, and oil; water; spares and tools; crew and equipment. No standard has as yet been established.

Operation

ballast—Any substance, usually sand or water, carried in a balloon or airship and intended to be thrown out, if necessary, for the purpose of reducing the load carried and thus altering the aerostatic relations. (Plate 6.)

bow-heavy—The condition of an airship which, when at rest in still air, trims with its axis inclined down by the bow. The term "bow-heavy" is preferred to "nose-heavy" in describing airships.

breathing—The passage of air into or out of an aerostat, due to the changing of its volume.

breathing stresses—Stresses produced in an aerostat by breathing. Of importance in the envelope and keel of a semi-rigid airship due to the interaction of envelope and keel when the envelope "breathes."

danger cone—A pennant on the wire cable of a captive balloon to warn aircraft of its presence. Usually a hollow cone of light cloth.

deflation—The act of removing gas and air from an aerostat.

deflation sleeve—Generally a sleeve or appendix made of fabric provided for the special purpose of facilitating the deflation of an aerostat. Also applied to the sleeve or appendix fitted in the lower lobe of a kite balloon and used to permit the rapid escape of air in the lobes when the balloon is hauled down. (Plate 5.)

gassing—The operation of replenishing a balloon with fresh gas to increase the purity or to make up for a loss of gas.

gassing factor—The quantity of aerostatic gas required to maintain an aerostat for one year. It is ordinarily expressed as a percentage of the gas volume.

hog—A distortion of an airship in which the longitudinal axis becomes convex upward so that both ends droop.

inflation—The act of filling a balloon or airship with gas.

sag—A distortion of an airship in which the longitudinal axis becomes concave upward so that both ends rise.

stern-droop—A deformation of an airship in which its longitudinal axis bends downward at the after end.

stern-heavy—The condition in which, in normal flight, the after end of an airship tends to sink and which requires correction by means of the horizontal controls. In this condition an airship is said to "trim by the stern." It may be due to either aerodynamic or static conditions or to both.

superheat—The amount by which the temperature of the gas in the envelope or gas cells of an aerostat is higher than the temperature of the surrounding air. If the contained gas has a lower temperature, the superheat is said to be negative.

trim—The attitude of an aerostat relative to a fore-and-aft horizontal plane. If the forward end is down, the aerostat is said to have "trim by the bow;" if the after end, it has "trim by the stern."

trim, to—To alter the attitude of an aerostat relative to fore-and-aft horizontal plane. If the endeavor is to force the bow down, the aircraft is "trimmed by the bow;" if the stern, it is "trimmed by the stern." It

the aircraft shows a tendency to sink by the bow end, it is said to "trim by the bow" or to be "bow-heavy;" if the tendency is to sink by the stern, it is said to "trim by the stern" or to be "stern-heavy."

Terms Common to Aerostats and Airplanes

Parts

balanced surface—A control surface which extends on both sides of the axis of the hinge or pivot in such a manner as to reduce the moment of the air forces about the hinge.

controls—A general term applied to the means provided to enable the pilot to control the speed, direction of flight, attitude, and power of an air-craft.

air controls—The means employed to operate the control surfaces of the aircraft.

engine controls—The means employed to control the power output of the engines. (Control of speed may be effected by the air controls or the engine controls independently, or by either in conjunction with the other.)

control stick—The vertical level by means of which the longitudinal and lateral controls of an airplane are operated. Pitching is controlled by a fore-and-aft movement of the sticks, rolling by a side-to-side movement.

control surface—A movable airfoil designed to be rotated or otherwise moved by the pilot in order to change the attitude of the airplane or airship.

elevator—A movable auxiliary airfoil, the function of which is to impress a pitching moment on the aircraft. The elevator is usually hinged to the stabilizer.

fin—A fixed surface, attached to a part of the aircraft, parallel to the longitudinal axis, in order to secure stability; for example, tail fin, skid fin, etc. Fins are sometimes adjustable.

fixed fuel tank—A fuel tank which is not intended or fitted to be dropped, as "slip" tanks are.

horn—A short lever attached to a control surface of an aircraft; for example, aileron horn, rudder horn, elevator horn.

inspection window—A small transparent window fitted in the envelope of a balloon or airship, or in the wing of an airplane, to allow inspection of the interior.

rigger—One who is employed in assembling and aligning aircraft.

rigging—The assembling, adjusting, and aligning of the parts of an airplane, or the attachment and adjustment of the car, rudders, valves, controls, etc., of an airship.

service tank—A fixed fuel tank near each power unit, into which fuel from other tanks is pumped and from which the fuel supplying the engines is drawn.

slip-fuel tank—A fuel tank which is provided with a device permitting the quick dropping of the tank and contents as a whole in case of an emergency. Fitted on both airships and airplanes.

stabilizer—A normally fixed airfoil whose function is to lessen the pitching motion. It is usually located at the rear of an aircraft and is approximately parallel to the plane of the longitudinal and lateral axes. Also called "tail plane." In aerostats—same as "fin." The lobes of a kite balloon are sometimes referred to as stabilizers.

tail group (or tail unit)—The stabilizing and control surfaces at the rear end of an aircraft, including stabilizer, fin, rudder, and elevator. (Also called "empennage.")

QUESTIONS FOR REVIEW

1. Describe principal parts of spherical balloon and give its uses.
2. What is the difference between hydrogen gas and helium gas and which is best for airships and why?
3. Describe briefly nature of helium, its cost and use.
4. Why is a kite balloon better than a spherical balloon for observation work when held captive?
5. Describe the main features of the rigid type dirigible and give important structural details.
6. Outline differences between semi-rigid and non-rigid types of dirigibles.
7. Consider briefly the varying spheres of economic usefulness of the dirigible and the airplane.
8. What is "water recovery" in a dirigible and why is it valuable on this type of aircraft and of no value on airplanes?
9. Name some advantageous features of airships.
10. What metal is used widely in airship construction and how is it used?

CHAPTER III

EARLY AIRPLANES AND GENERAL DESIGN CONSIDERATIONS

Henson Airplane—Philips' Multiplane—Maxim's Flying Machine—Ader's and Other Machines—First Flights of the Wright Brothers—Lack of Speed an Early Drawback—Plane Forms—Langley's Tests—Bird and Plane Form Compared—Airplane Moves in Three Planes—Bird Flight Difficult to Imitate—Comparing Airplane and Bird Flight—Table III, Beaufort Scale of Wind Force—Plane Balancing Principles—Airplane Control Methods—Use of Vertical Rudder—Some Early Airplane Designs—Some General Design Factors—Power Requirements of Airplanes—Table III A, Power Requirements of Early Airplanes.

Henson Airplane.—One of the first machines built to operate on airplane principle was devised by an Englishman named Henson, and was built in 1843. This consisted of a light framework of wood, covered with silk, about 100 feet broad and 30 feet long and was slightly bent upward at the front. A rudder approximating the shape of the tail of a bird, which was 50 feet long, was used to steer it in a vertical direction. The car was placed below the main plane and contained the steam power plant and also provided room for the passengers. Propulsion was to be obtained by two propellers which were placed on either side of the car, and it was proposed to regulate the speed of these. By having the propellers mounted on a universal driving joint it was proposed to assist in turning the machine to the right or left by turning the propellers, so that the thrust would be exerted on an angle instead of in a straight line, as was required to secure normal flight. Owing to very low horsepower and great weight of the power plant, the engine developing but 20 H.P., the machine was not capable of leaving the ground. Had the modern light-weight high-powered internal combustion engine been available, there is no doubt but that this machine would have been able to leave the ground under its own power, though, of course, in the light of our present knowledge its speed would have been low, its flying action very poor, and it would not have been capable of making any sustained flight.

Philips Multiplane.—Horatio Philips, another Englishman, built a very peculiar form of airplane flying machine in 1862. This model had a supporting wing area composed of a very large number of very narrow surfaces with a long advancing edge, the plurality of planes being carried in a frame, so that the entire contrivance resembled a huge Venetian blind. The height of the frame was about 10 feet, the breadth was 21 feet. The whole was mounted on a wheeled carriage shaped like a boat which was about 25 feet long. It was operated over a circular board track and was anchored by a rope in the model to the middle of the track. The weight was less than 300 pounds and tests show that a dead weight of 72 pounds placed over the front wheels could be lifted 30 feet in the air when proper speed had been attained. This proved that airplane surfaces were

capable of supporting weight by air reaction. Owing to trouble with the power plant very little else was done. His early work, however, was a basis from which later types of aerofoils were designed as he proved that planes having a long entering edge in relation to the chord were most efficient.

Maxim's Flying Machine.—A well-known scientist, Sir Hiram Maxim, carried out some very interesting experiments in 1881 with a very large flying machine built on airplane lines, which is said to have cost over $100,000. This consisted of a large main supporting plane with a number of smaller aerofoils to the right and left of it, the whole having an available supporting area of 3,875 square feet. The planes were connected to a platform 40 feet by 8 feet by means of a framework built of thin-walled steel tubes, this platform forming the support for the boiler and engine and absolutely no provision was made for streamlining as the effect of parasitic resistance was probably unknown at that time. It is only since the World War that this subject has been given the attention it deserves. The diameter of the propellers was over 17 feet. The vertical movement of the machine was controlled by two horizontal planes, one of these being placed at the front of the machine, the other at the back. Horizontal movements were to be controlled by two planes inclined to one another at an angle of about 8 degrees and arranged on either side, so as to be capable of being raised or lowered. The result of this movement was to shift the center of gravity and consequently alter the direction of motion. The entire machine weighed 7,000 pounds, and in the experiments it was mounted on four flanged car wheels and operated on a railroad track. In order to control the upward motion of the machine an overhead rail was placed over the top. With a steam pressure of 300 pounds (this machine being driven by steam, as it was the only power plant then available) the machine rose from the lower rails and came into contact with the upper ones. During a test made some time later the upper rail was broken as a result of the impact and the machine flew across a field, and on landing was partially destroyed. This is the first record of a successful flight by a heavier-than-air machine in which the propulsive power was furnished by a power plant forming a part of the machine structure. The dynamometer test showed that a weight of 5,000 pounds would have been lifted in addition to that of the machine and as can readily be seen, had the light weight internal combustion engine been available, it is conceivable that aerial flight might have been solved years earlier than it was. It was about this time that Daimler was perfecting his first crude internal combustion motor, which at that time was not built in powerful and light multiple-cylinder forms, but only in the simple single-cylinder and two-cylinder V types of limited horsepower that were considerably heavier than modern engines of fifty times their power. These experiments would lead one to believe that it is possible to build airplanes of considerably greater weight than any which have been so successful in modern flying and very large aircraft of the heavier-than-air type have been proposed that will make our modern Goliaths of the air with their spread of 120 feet or more, appear as pygmy planes in comparison.

Ader's and Other Machines.—Among the later creations which must be mentioned is the type shown at the Paris Exposition in 1900, which was devised by a French engineer and electrician named Ader. The planes were of a peculiar form and in the nature of wings which could be folded back. Two propellers were employed, each with 4 blades, and despite the fact that compressed-air motors were utilized to drive the propellers and that the machine weighed over 1,000 pounds, it managed to make short flights and demonstrated that it was capable of lifting its weight from the ground. An Austrian by the name of Kress tried out a machine near Vienna in 1901 with results that gave considerable promise, and the experiments made by the late Professor Langley at Washington, D. C., resulted in the first flight of over a mile by a heavier-than-air craft. This was made by a model plane of his design on December 12, 1896. The experiments of Prof. Lilienthal, a German, who was studying the problem of soaring by means of gliders and the experiments of the Wright Brothers, in this country, produced real results that were later turned into account in building power propelled airplanes.

First Flights of Wright Brothers.—The flights made in 1903 by the Wright Brothers, who built an airplane which was equipped with a motor of their own construction, was really the first development of a type that was at all similar to the machines used at the present time. Even at the early stages of the development they were able to make flights of over 1,000 feet, but owing to the secrecy with which they worked and the isolated points at which their experiments were carried out, but little was thought of their accomplishments by the world at large. Later developments have proved that even at that early date they were far ahead of their contemporaries, because they were working on independent lines and developing new features of construction instead of trying to improve or re-adapt the principles that had been discovered to apply to the very early types of unsuccessful flying machines. It will be understood that in referring to these as successful flights the description is but a relative one, because at that early date any machine that would leave the ground and fly for a few hundred feet at an elevation of 8 or 10 feet and at 40 miles per hour was considered to be a real flying machine. Today, almost any schoolboy, handy with tools, can build a light plane in his back yard and install a motorcycle engine for power and make faster and longer flights than that. He has a mass of data to guide him and numerous successful machines to copy, not to mention various firms who will supply him with plans and materials of construction at reasonable prices.

Lack of Speed a Drawback.—It required long development and continuous experimenting to develop the modern forms which are capable of making sustained flights for hours at a time at extremely high speeds. One of the difficulties met with in the early types of machines was the limitations imposed by power plants of inadequate capacity. A theoretical consideration by the early engineers working on mechanical flight outlined that flight would be possible with considerably less power than is now utilized, but the machines of that period were very flimsily built and therefore very light and did not fly at very high speeds, so that power plants of 30 or 40 H.P. were sufficient to handle the requirements of flying under favorable

conditions. It was learned later that reserve power was needed in order to secure flights and to overcome unfavorable atmospheric conditions. In order to secure relative speed it is imperative that the speed of flight be very much greater than any of the winds one would be apt to meet with while flying. A table showing wind force and how it can be measured is appended. It will be evident that if a machine capable of flying at a speed of 45 miles per hour encountered a wind of equal speed and flew into it, that the machine would remain practically stationary relative to the ground and would not advance. A machine with a high flying speed which calls for considerably more flying speed than was provided at that time would, of course, be able to make progress against such a wind. The early airplanes were only flown on calm days, our modern airplanes keep going through tempest or storm because they have sufficient power. Bert Acosta, a government instructor during the World War at Mineola, L. I., and a pioneer aviator who could fly and still is frequently called upon to fly the weirdest types of airplanes, used to say in jest that he would undertake to fly a drop side kitchen table if fitted with enough power and controls. One of his late achievements was the breaking of the world's endurance record by keeping a Wright-Bellanca Monoplane in the air for 51 hours and 31 minutes in April, 1927. This record is shared with Clarence Chamberlain another well known pilot who accompanied him. Acosta was also the pilot of the Fokker three-engine monoplane America which was commanded by Commander Byrd and navigated by Lieutenant Noville of the U. S. Navy on a flight from New York to France.

Plane Forms.—The effect of using wings or planes of the same area but of varying shapes and forms is marked, and also with those of different aspect ratio and aerofoil section, but in tests the actual results obtained were so much different as to be the cause of considerable comment. There was no question but that the form of the wing of a bird when extended in soaring flight had proportions that could be followed to advantage by the designer of airplanes; however, the curves of a bird's wings are not easily duplicated in man-made machines, so that various forms of aerofoils have been devised that give really good results when driven through the air at sufficient speed by the thrust or push of a propeller. Experiments have demonstrated that within certain limits the supporting wings should be long when viewed from the front, and short when seen from the side. The best proportions have never been definitely determined and vary in many of the successful creations. The usual aspect ratio is about 6 or 7 to 1,—that is, the spread of the wing from tip to tip is 6 or 7 times the depth or width, measured along the chord.

Langley's Tests.—Professor Langley made some interesting tests to demonstrate that a plane having a wide advancing edge was the most efficient. These, of course, were made with small models. A plane with a width of 6 inches and a length of 18 inches moving at the rate of 45 miles per hour fell vertically 4 feet in 7/10 of a second. The same plane, when the advancing edge was 18 inches and the length was 6 inches, has the same supporting area as the other and when moving at the same velocity it fell vertically 4 feet in two seconds, demonstrating beyond a doubt that the sustaining power of the form having the wide advancing edge was

about three times that of the same plane when it advanced with the narrow edge first. These crude and early tests were made before the modern wind tunnels were devised. With a wind tunnel a complete model plane, balloon or boat hull, aerofoil or any streamline form can be tested under conditions approximating actual flight and the forces acting on it and reactions on the structural parts can be measured with an accuracy that would have been greatly appreciated by the pioneer designers and that would have greatly hastened the advent of aerial navigation had such facilities been available.

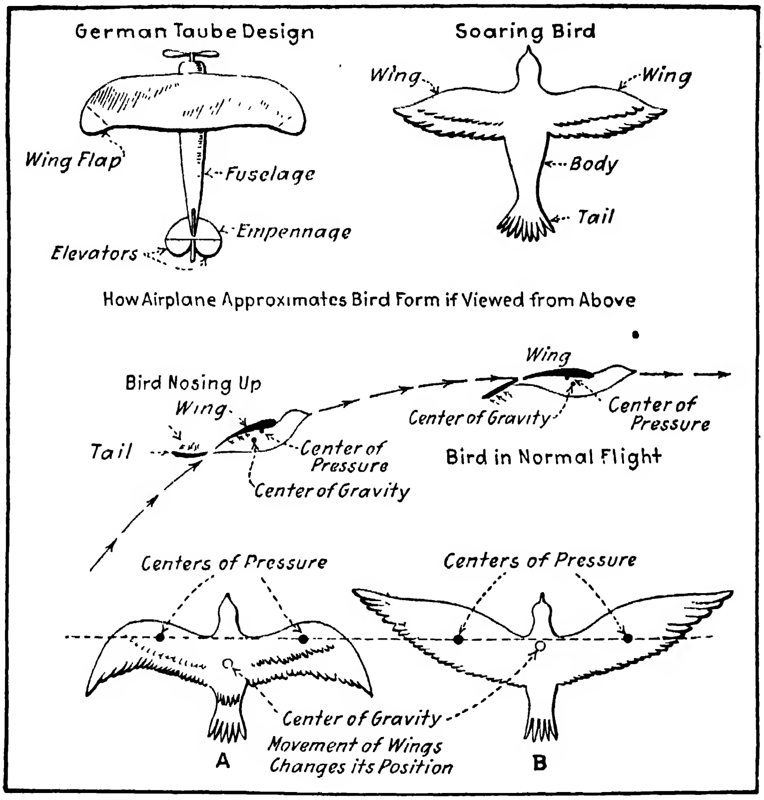


Fig. 14.—A Bird can Shift the Relation of Pressure and Gravity Centers by Wing and Tail Movements and Secure Changes of Direction in a Vertical Plane with Ease.

Bird and Plane Form Compared.—If one compares the form of a bird with that of some of the late airplanes, as at Fig. 14, it will be apparent that they are somewhat similar in form, because both have a wide advncing edge or wing spread and that the plane or wing is comparatively short, and, as will be evident, the bird can utilize its tail as an auxiliary wing which aids and directs its flight. The section of a bird's wing is similar, in the main, to the cantilever monoplane, being thicker at the point of attachment to the body than it is at the wing tips. While airplanes have flown successfully with wings of rectangular plan, the most efficient of our modern

designs utilize wings which not only taper in sectional area but also in plan. It is necessary to provide some form of rudder or auxiliary plane on an airplane in the form of an aerofoil which can be lifted or depressed, so that the air will act on the top or bottom of its surface, depending upon the direction it is desired to fly in. The bird has no surface that corresponds to the vertical rudder necessary on an airplane, because it is possible for it to flex its wings and to flap them simultaneously and thus secure

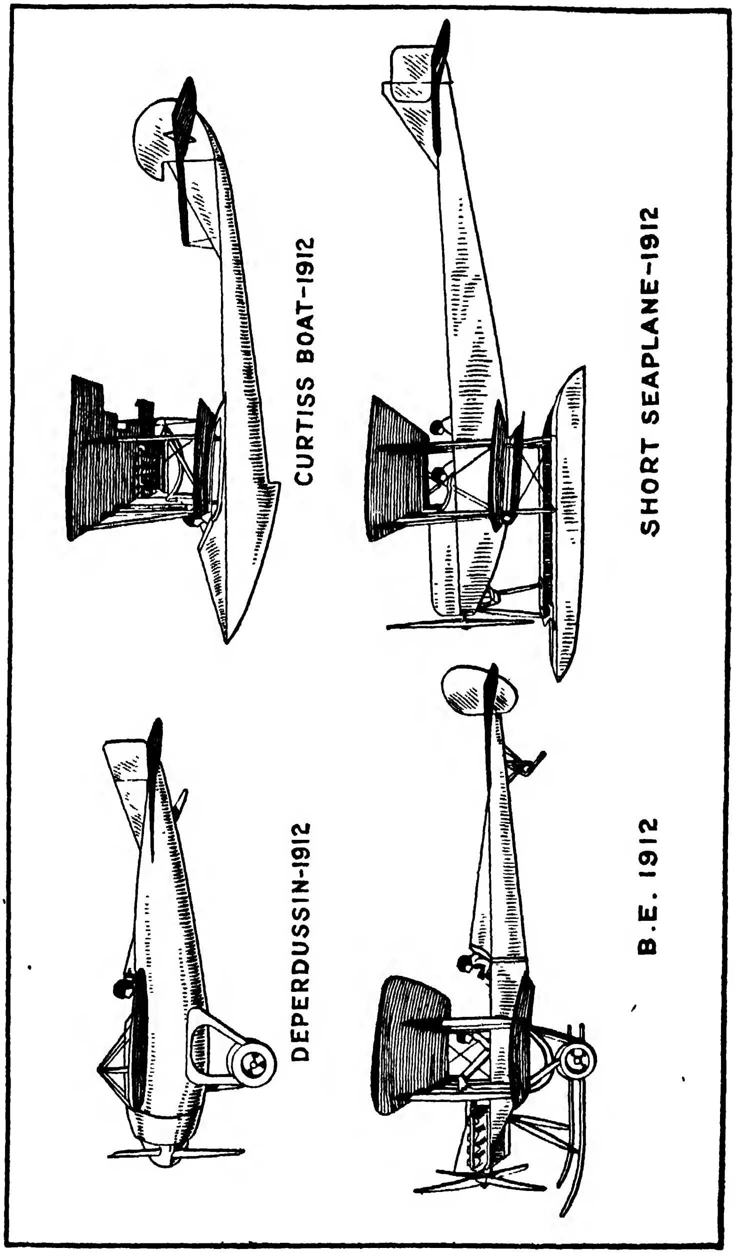


Fig. 15.—Successful Airplanes and Seaplanes of Early Development that Suggested Modern Designs.

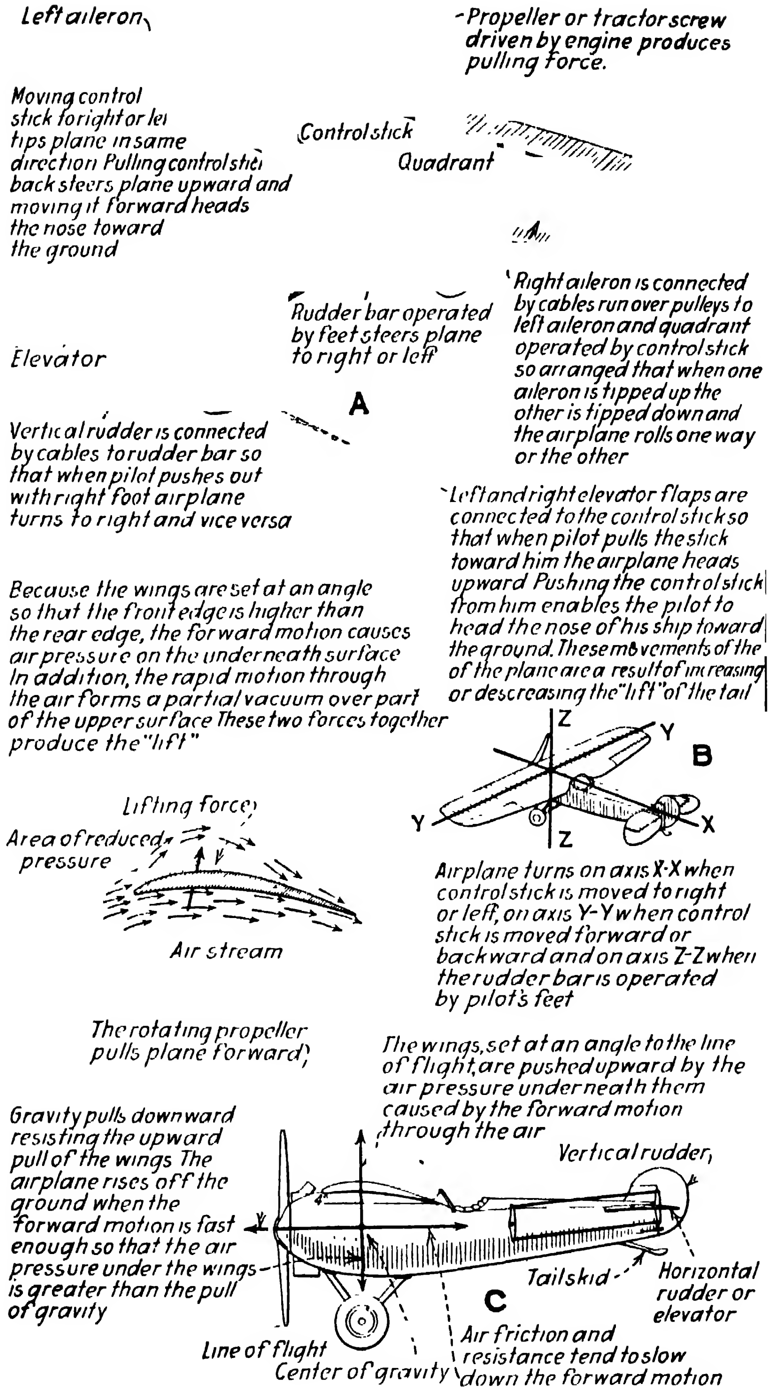


Plate 10.—Diagrams Explaining Control of Modern Airplanes. Perspective Phantom View. A—At Top Shows how Control Flaps are Actuated by Flexible Cables Passing over Pulleys. B—Depicts Axes on which Airplane Moves. View at C Shows Forces Acting on Airplane in Flight.

propulsive effort and change the direction at the same time. It is also possible for a bird to move its wings forward or back and alter the center of pressure as well as the angle of attack in a way that would be very difficult for man-made mechanism to imitate even approximately, because the bird does it instinctively and probably without thinking about it. This is not possible with the planes of an airplane which must be immovable relative to the fuselage in order to secure the necessary strength. It is possible, however, to turn an airplane without the use of the vertical rudder by merely working the ailerons which would correspond to some degree to the flexing of the bird's wing tips. The vertical rudder is necessary, however, to make good turns in the man-made flying machine, even though it can be dispensed with in nature's model.

Airplane Moves in Three Planes.—There are really three axes about which an airplane structure can operate, so that three distinct sets of control surfaces are required. Reference to Plate 10 will show these axes and also how the various control members operate in a typical monoplane. This diagram was originally prepared by the writer for use in Popular Science Monthly in which it first appeared. In the usual tractor biplane form all of the control planes are at the rear of the fuselage and wings. Those at the tail are called the "empennage." The elevator, which consists of two flaps capable of moving up and down, is at the extreme rear of the fuselage and controls "pitching" or up-and-down movements. The rudder, which has a vertical surface, is utilized for the turning or "yawing," as it is called. The balancing or "rolling" control, as it is called, is produced by the ailerons or wing flaps. The main control surfaces are clearly shown at Fig. 16 and Plate 10 in their proper relation to the rest of the machine, and a view of a typical empennage is shown at Fig. 17. This will be considered more in detail in a later chapter.

Birdflight Difficult to Imitate.—When one compares the flight of birds with the principles that underlie the support of an airplane in the air, it is only because the bird is Nature's flying machine and such comparisons are not fair because a part of the supporting force through which a bird flies is obtained by the flapping of wings, which so far has not been successfully imitated by man-made mechanism. It is not strictly a flapping movement, but one that combines a flapping to provide lift with a forward thrust. Another thing that can never be imitated is the peculiar instinctive co-ordination of various body parts by which a bird can change its center of gravity in its relation to the center of pressure and secure up or down flight by movement of its head, tail or wings. A comparison between birds and airplanes can only be made when one considers soaring birds and then only as long as the creature supports itself by changing the relation of its wings and body so as to secure the support it needs from varying air currents,—obviously as soon as the bird starts flapping its wings it ceases to act in the same way as an airplane, which cannot have any relative movement of its supporting surfaces or shift weights so that changes of the center of gravity may be obtained though the control surfaces can cause center of pressure movement on the wing within limited bounds by changing the angle of attack or the incidence of the wing, as will be described in proper sequence. Once located, the center of gravity of an airplane

remains the same though the relation of the center of pressure to the center of gravity may change.

Comparing Airplane and Birdflight.—In an airplane, the fuselage is suspended between wings on each side which may be single, in pairs or in

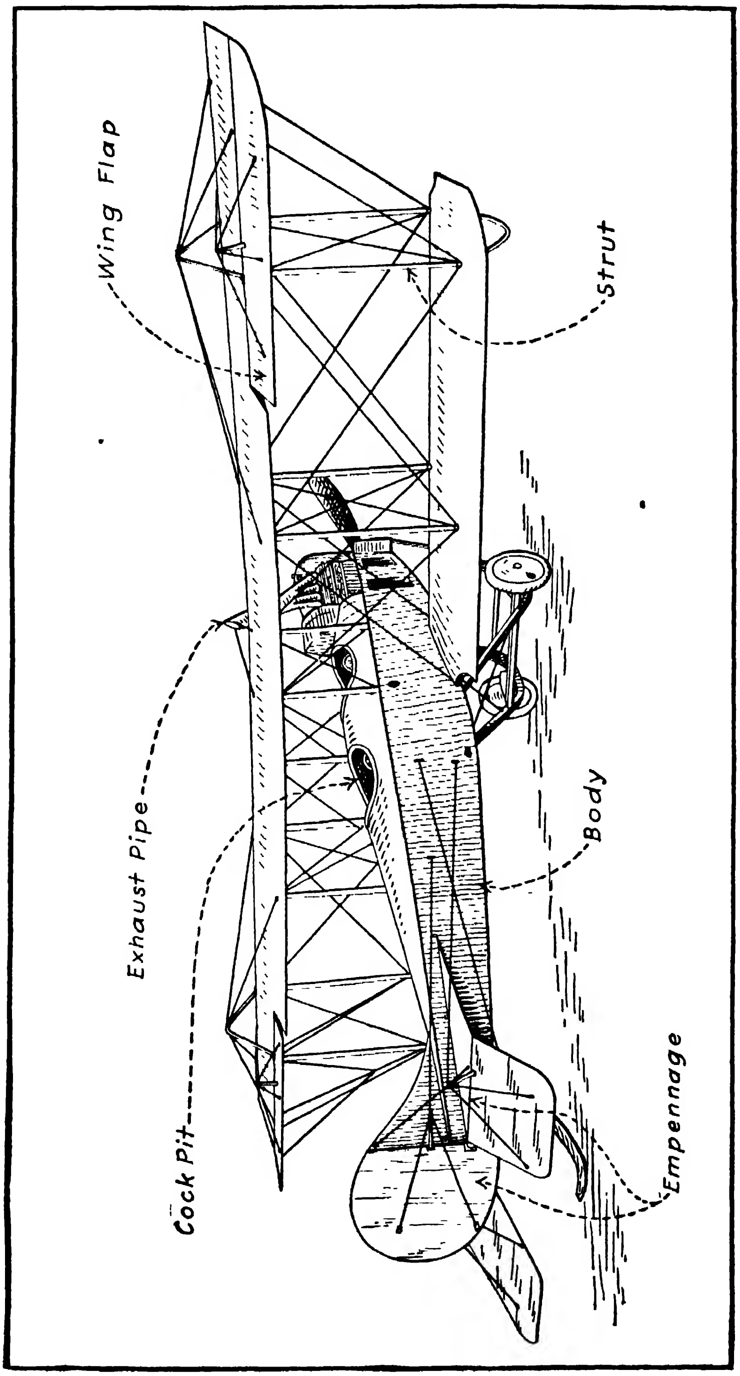


Fig. 16.—The Wing Flaps Aid in the Control of Lateral Balance.

triplicate, depending on whether the machine is a monoplane, biplane or triplane and as we have previously discussed, the machine may even have four or more surfaces. Modern practice for planes of ordinary size is towards the simplest or monoplane structure and few airplanes are built that utilize more than a pair of wings on each side of the fulselage. The principle of the wide advancing edge is made use of—just the same as obtained in nature's creation. In a bird, which is always a strictly monoplane design because nature's plan seems to be always to provide maximum possible efficiency in its living mechanisms, the body is sustained between two wings that have sufficient supporting area to perform the necessary functions of sustentation during soaring flight, but the control of this is so delicate that by the simple movement or flexing of feathers at the wing tips, not necessarily the movement of the wings or of the body, it is possible to decidedly change the poise or balance of the bird in the air.

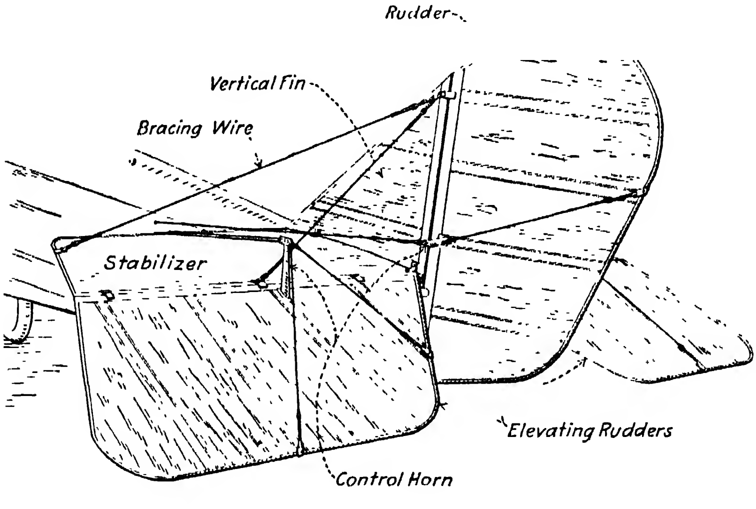


Fig. 17.—Typical Empennage of a Modern Flying Machine Showing Various Parts.

The application of such natural force is instinctive with a bird and the utilizing of speed or wind velocity is all performed automatically without materially affecting the progress of the creature. The fact that this instinctive control is not impossible of attainment by man can be shown by the instinctive balancing which obtains when one becomes familiar with bicycle riding—the unconscious movement of the body, so easily accomplished by the rider who has had considerable experience, is very difficult for the novice to acquire, and even after several years' rest it is possible for one who is familiar with bicycle riding or who has learned it to get on a machine and ride off without any trouble.

Of course, the mass of a modern airplane is too great to be affected by any unconscious movement of the operator, though this principle of leaning the body to secure equilibrium was used in early soaring gliders and also in the old control system of Curtiss machines, where a shoulder rest which

could be rocked from side to side was connected to the ailerons or balancing flaps. The new system of control, however, does not utilize movements of the entire body, though an inherent sense of equilibrium is absolutely necessary in order that the aviator may tell when his plane is not flying as it should, such as having one wing lower than the other, or climbing at too steep an angle. When high up in the air, there is nothing to

TABLE III

Wind

From Beaufort Scale of Wind Force

General Description of Wind	Specification of Beaufort Scale For Use on Land Based on Observations Made at Land Stations	Mean Wind Force at Standard Density: Mb.	Mean Wind Force at Standard Density: Lbs. per Sq. Ft.	Equivalent Velocity in Miles per Hour
Calm	Calm; smoke rises vertically.........	.00	.00	0
Light air........	Direction of wind shown by smoke drift, but not by wind vanes.......	.01	.01	2
Slight breeze....	Wind felt on face; leaves rustle; ordinary vane moved by wind...........	.04	.08	5
Gentle breeze...	Leaves and small twigs in constant motion; wind extends light flag....	.13	.28	10
Moderate breeze.	Raises dust and loose paper; small branches are moved...............	.32	.67	15
Fresh breeze....	Small trees in leaf begin to sway; crested wavelets form on inland waters	.62	1.31	21
Strong breeze...	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty................	1.1	2.3	27
High wind......	Whole trees in motion; inconvenience felt when walking against wind....	1.7	3.6	35
Gale	Breaks twigs on trees; generally impedes progress	2.6	5.4	42
Strong gale.....	Slight structural damage occurs (chimney pots and slates removed)......	3.7	7.7	50
Whole gale.....	Seldom experienced inland; trees uprooted; considerable structural damage occurs.......................	5.0	10.5	59
Storm	Very rarely experienced; accompanied by widespread damage.............	6.7	14.0	68
Hurricane	....	8.1	Above 17.0	Above 75

compare this to except certain parts of the machine, which practice and observation tells the operator must occupy a certain position when in normal flight. Instruments have been devised to give this information to the pilot so that in a fog or when flying after dark or in a storm, one can

determine whether his airplane is flying in a straight line or turning a corner, whether it is banked, ascending or falling or riding on an even keel. These instruments are described and illustrated in a special chapter on Aircraft Instruments. We have seen that a slight angle of inclination is necessary to obtain sustentation with the expenditure of a moderate amount of power and that this angle of inclination is constantly varying, due to the control elements.

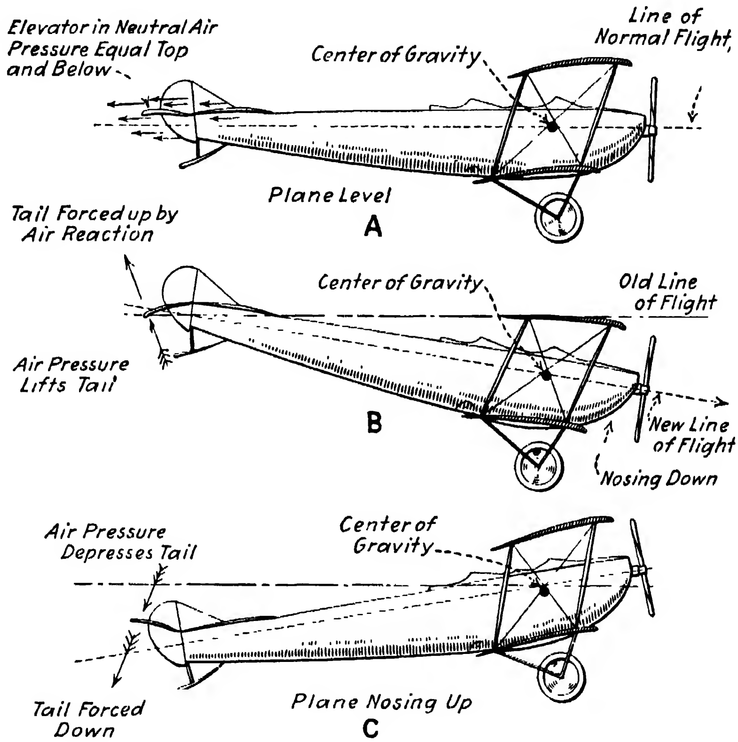


Fig. 18.—How the Elevator Controls the Direction of Flight.

Plane Balancing Principles.—The balancing of a plane is not difficult to understand if one is familiar with the underlying principles of simple levers. It is known that the smaller the distance the weight to be lifted is from the center of support or fulcrum of the lever and the more the distance is from the fulcrum to the point where the power, of lifting force is to be applied, the smaller the amount of force that is necessary to exert a given power. For example: assume a lever that had its fulcrum located 1/5 of the distance from the front end and 4/5 from the rear end. If one wished to lift 20 pounds at the short end, it would be necessary to exert but 5 pounds at the longer end of the lever to do this, because the power applied is multiplied by the length of the arm leading to the fulcrum point. An airplane fuselage may be considered as a lever having the position of the control surfaces so arranged that the air pressure on the empennage will

produce a lift or depression that will cause the machine to rock around its supporting point (which is called the center of gravity) between the wings. The farther away from the center of gravity the control surfaces are, the less their area needs be, conversely; the nearer they are the larger the area must be. This point is but briefly touched upon here and will be considered more completely in a later chapter.

Airplane Control Methods.—The control of the airplane is easily accomplished by the operator by means of the auxiliary surfaces which may be disposed horizontally for controlling movements in a vertical plane, such as the elevator flaps; and disposed vertically for controlling turning to the right or left as is the vertical rudder. Horizontal flaps for balancing are.

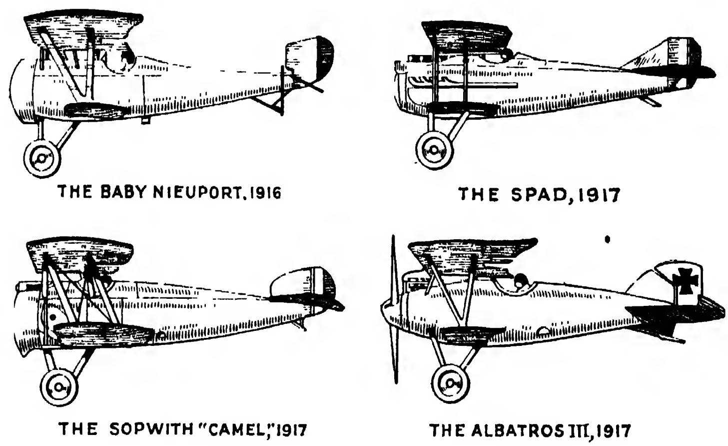


Fig. 19.—Typical Single-Seat Fighting Scouts of French, English and German Design that have been Built in Large Quantities.

carried at the rear ends of the wings to balance the machine. The manner in which the elevator operates can be readily ascertained by reference to the accompanying illustration (Fig. 18) which shows three positions of a tractor biplane. The normal position at A shows the machine flying along the normal line of flight, but the elevator is in a neutral position so that the air pressure is equal at the top and bottom. This, of course, produces no movement up or down of the tail. At B the elevator position has been changed so that the air currents lift under the bottom of the elevator; the resulting air pressure reaction lifts the tail of the machine up and causes the front end to nose down. At C the position of the elevator is reversed, that is to say, it is inclined in such a way that the air current presses upon its top surface. This produces pressure, which tends to force the tail down and lift the nose of the machine up. The center of gravity of the machine is always considered the equilibrium point about which the lifting force at the tail acts. By inclining the elevator up or down we are able to lift or depress the tail of the machine and produce a resulting or opposite action at the front end of the machine. For example: if the tail

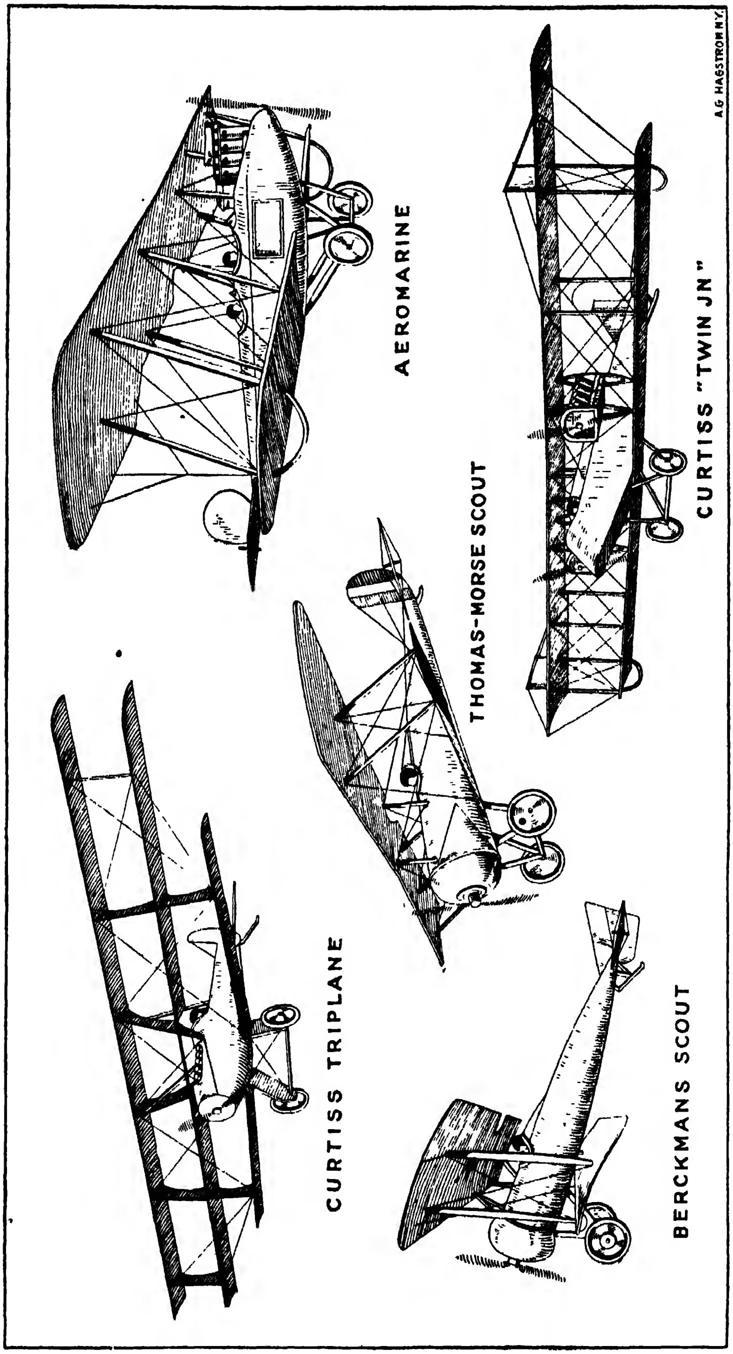


Plate 11.—Practical Early American Airplanes of Varying Design and Power Showing Appearance in Flight.

is forced down, the nose will be forced up and the machine will climb. If the tail is forced up the nose will be forced down and the plane will move on a downward path. When the surfaces are left in a neutral position, so that the air pressure is equal at the top or bottom, the plane will fly along the normal line of flight.

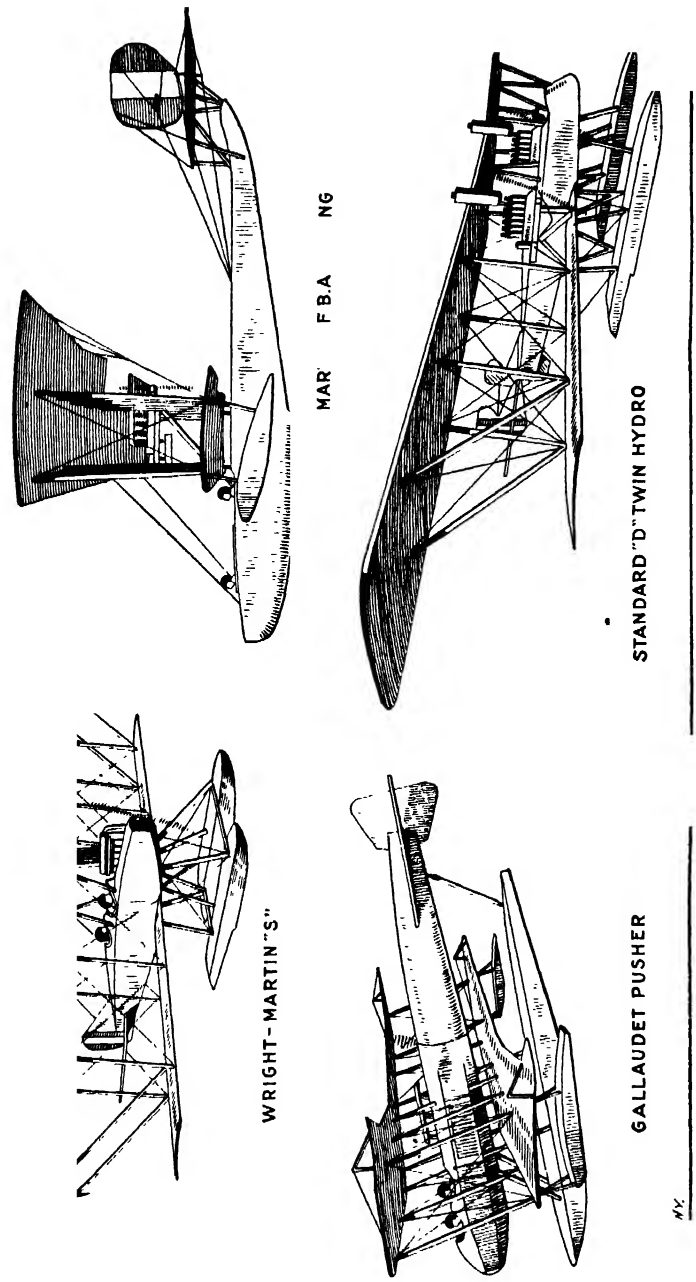


Plate 12.—Pre-War Designs of Ame aplanes and Flying Boats that have Made Practical Fligh

Use of Vertical Rudder.—The same action that has just been explained in relation to the elevator will work in about the same way when the vertical rudder is tilted to the right or to the left. The reaction of the air against the inclined surface naturally pushes the back end of the machine

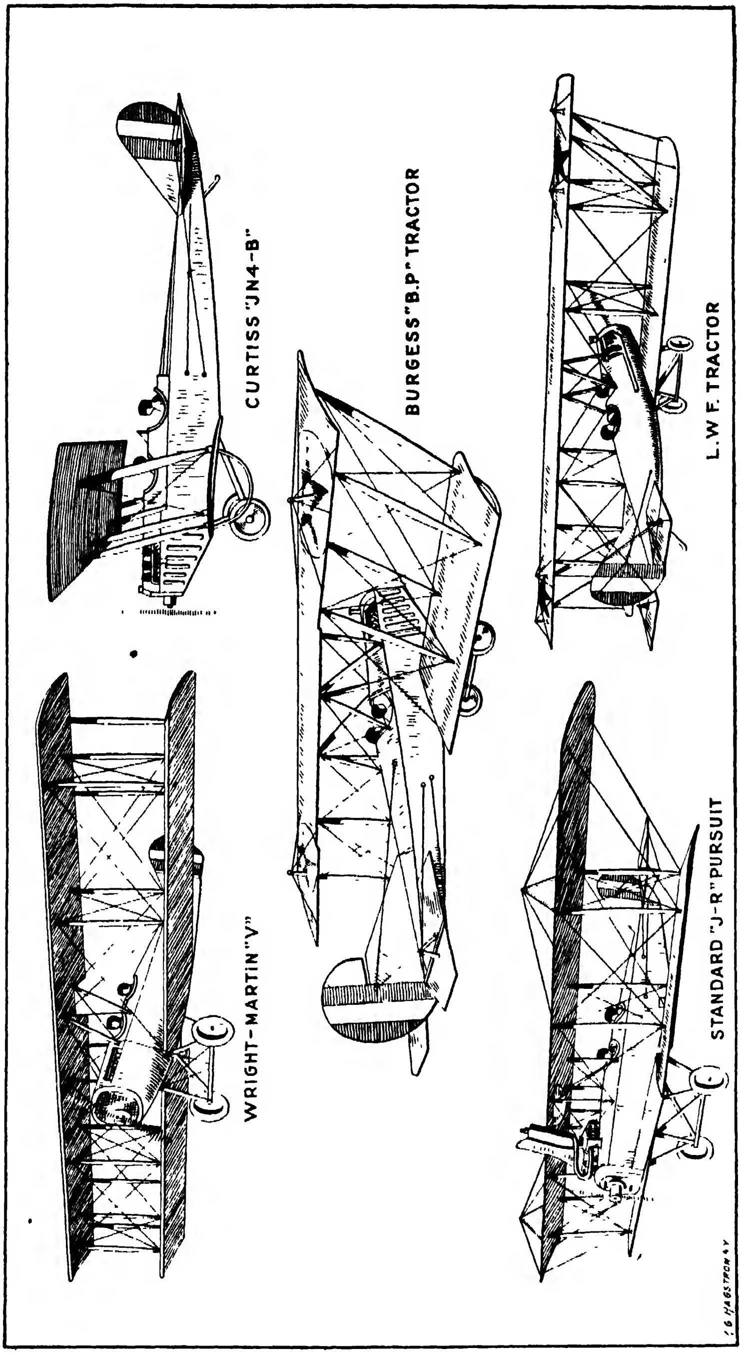


Plate 13.—Drawings Showing Typical Airplanes Developed before the War that were Suitable for Practical Cross-Country Flights.

around in the direction in which the force is acting. In this way it is possible to steer the airplane in the air just as a boat is steered in the water. The remaining control, which is that for balancing the machine or maintaining it in equilibrium, is obtained by the wing flaps which are carried at the rear extremities of the wings in all of the modern machines. (See

Figs. 16 and 19.) In some of the earlier airplanes the ailerons were held by the struts and were carried at a point approximately midway between the supporting planes. It will be evident that as long as the wing flaps are allowed to remain in a neutral position that there will be no more lift on one wing than on the other. (See Plate 10.) Let us assume that it is possible to raise one wing flap and to lower the one on the other side, as in banking when making a turn. The wing flap or aileron on the side that is to be high is moved so that the pressure will act on its lower surface while the corresponding member of the wing that is to be lowered is moved in such a way that the air pressure acts on its upper surface. The function of the wing flaps or balancing ailerons is not only to permit the operator to right the machine when it is tilted by a gust of wind, but also to tilt the machine purposely when it is desired to bank when the machine leaves a straight path and describes a circle, under the influence of the vertical rudder controlled by the rudder bar actuated by the pilot's feet.

Some Early Airplane Designs.—The modern airplane, upon hasty inspection does not seem to vary much in design from the types built before the War. In general outline, equivalent types are apparently the same, but there has been marked improvements made in structural design that are not apparent on first glance. For instance, the very careful streamlining to reduce parasitic resistance is not always noticed by the layman, nor is the change in fuselage or body contours that so greatly reduce frictional drag. Before describing features of modern aircraft it seems desirable to show some airplanes designed before the World War and while it was in progress so there can be a basis of comparison with modern forms to be shown in a later chapter. All types of planes are shown ranging from training and scout planes to large flying boats and bombing planes. (See Plates 11 to 15 inclusive.) It will be apparent that some very large airplanes were built during that period.

Some General Design Factors.—The reader not versed in aeronautical science may wonder how a designer arrives at the best type of airplane for a given service and what rules determine his choice of design. There is no best type of airplane anymore than there is a best type of automobile, motorboat or kitchen stove. The work the airplane is to do and what it is to cost are primary considerations. Certain factors should not be departed from to secure good design. Wing loadings, horsepower loadings, flying and landing speeds, maneuverability, capacity, reliability, comfort, nature of terrain over which the plane is to be operated; all these are points that must be taken into consideration by the designer. There is a mass of data available for the designer and so many different forms of machines have been built and tested that it is difficult for one versed in the art to tell just what new combination of body, lifting and control surfaces will be evolved. Almost any arrangement, if provided with sufficient power will leave the ground and fly, but all do not fly with equal efficiency or stability.

An important consideration is the relation between the useful load to be carried and the weight of the machine. Practically all airplanes have a 40-60 ratio or thereabouts. The dead weight will be from 60 to 65 per cent of the total weight. Some designs are more efficient than others and

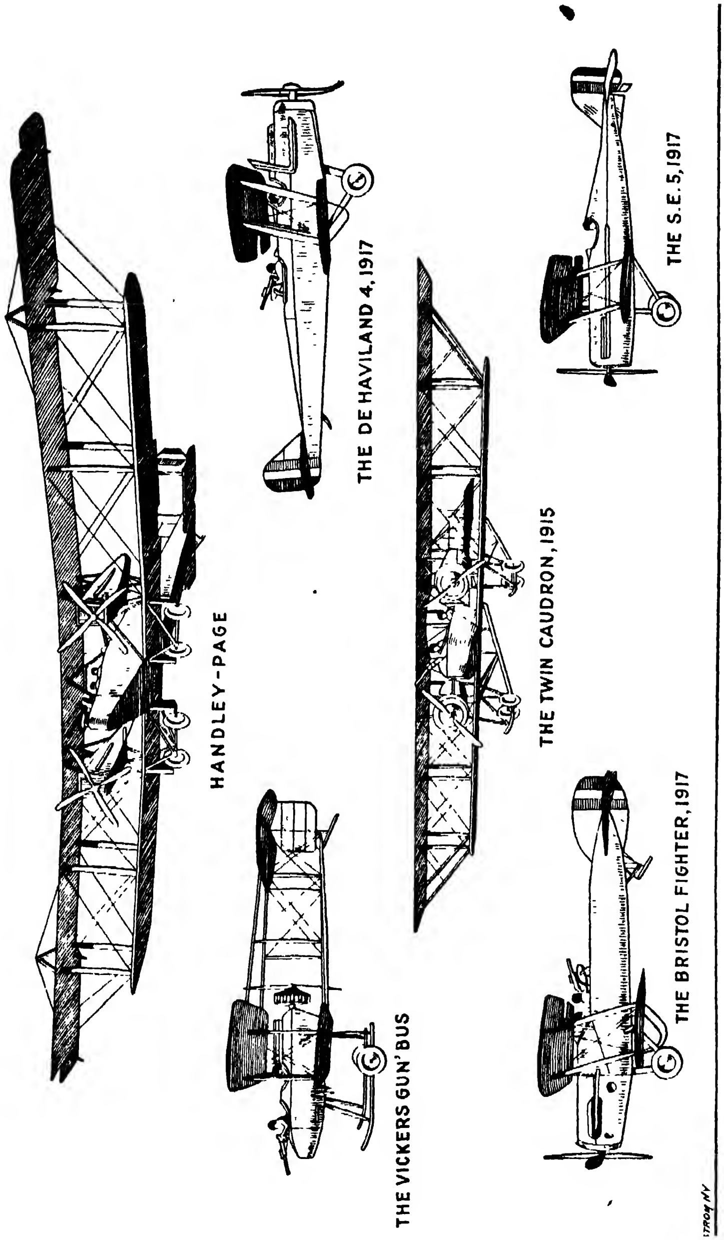


Plate 14.—Early Foreign Airplanes Designs that Incorporate Many Features of Modern Aeronautic Practice.

will fly faster and with less power. The less the horsepower required for a given weight, the lower the fuel consumption and the greater the radius of action on a given amount of fuel. A typical distribution of dead weight for the various parts of an airplane is shown at Fig. 20, but these figures do not apply to all airplanes. Some types will have a radically different

proportioning of values. The figures given are merely so one can have a basis from which to start. If will be evident that any design that increases the amount of useful load carried in proportion to the dead weight is a step forward in the right direction. A plane that would weigh half of the total load so that a 50-50 basis could be obtained would be a great advance, because while the decrease in dead weight is only 10 per cent of the total weight, the carrying capacity is increased from 40 to 50 per cent of the total weight and a 25 per cent increase in useful load is obtained.

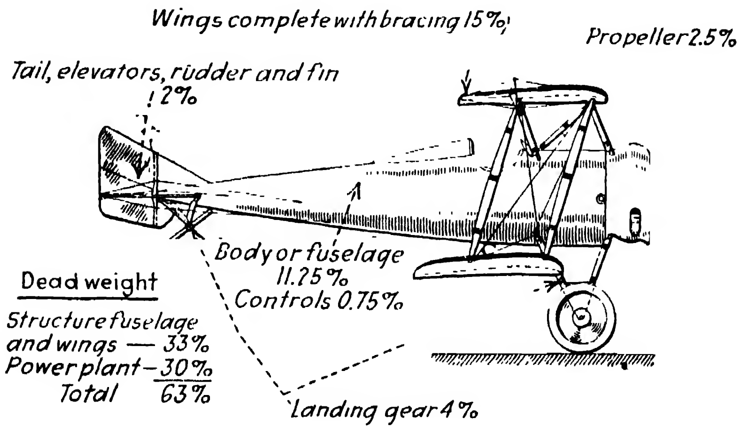


Fig. 20.—Side View of Airplane Showing Percentage of Weight of Various Structural Elements Comprising the Assembly. This Varies in Different Designs, but Proportions Shown are Typical of Modern Practice.

In starting to design an airplane, therefore, it would seem that the useful load to be carried would be the first consideration. If this was placed at one ton, or 2,000 pounds, the designer would know that in the light of our existing knowledge that his airplane would weigh at least as much again and probably more. The total load to be carried would probably be about 5,000 pounds. Now he must determine what type of airplane he will build, monoplane or biplane. Wing loadings now enter into consideration. Airplanes have been built with a wing loading as low as 4 pounds per square foot, and values of 10 pounds per square foot are not unusual. Now he must consider how fast he wishes to transport this load because a high lift wing is usually a slow wing. He may take a value between the two extremes for his wing loading, say about 7 pounds per square foot. With this factor decided, he knows he must have an area of $\frac{5000}{7} = 714$ square feet to support the load. A monoplane wing of good proportions to have this area would be roughly 60 feet span by 12 feet chord or 70 feet span by 10 foot chord. A single surface would be too large in his opinion so the designer decides he will build a biplane structure. That means two wings of 350 square feet each. This permits a material reduction in the spread of the proposed plane as if it is 50 feet spread, the chord will be 7 feet or thereabouts. Some wing curves are more effective than others so he must choose that best in his opinion, supported by test.

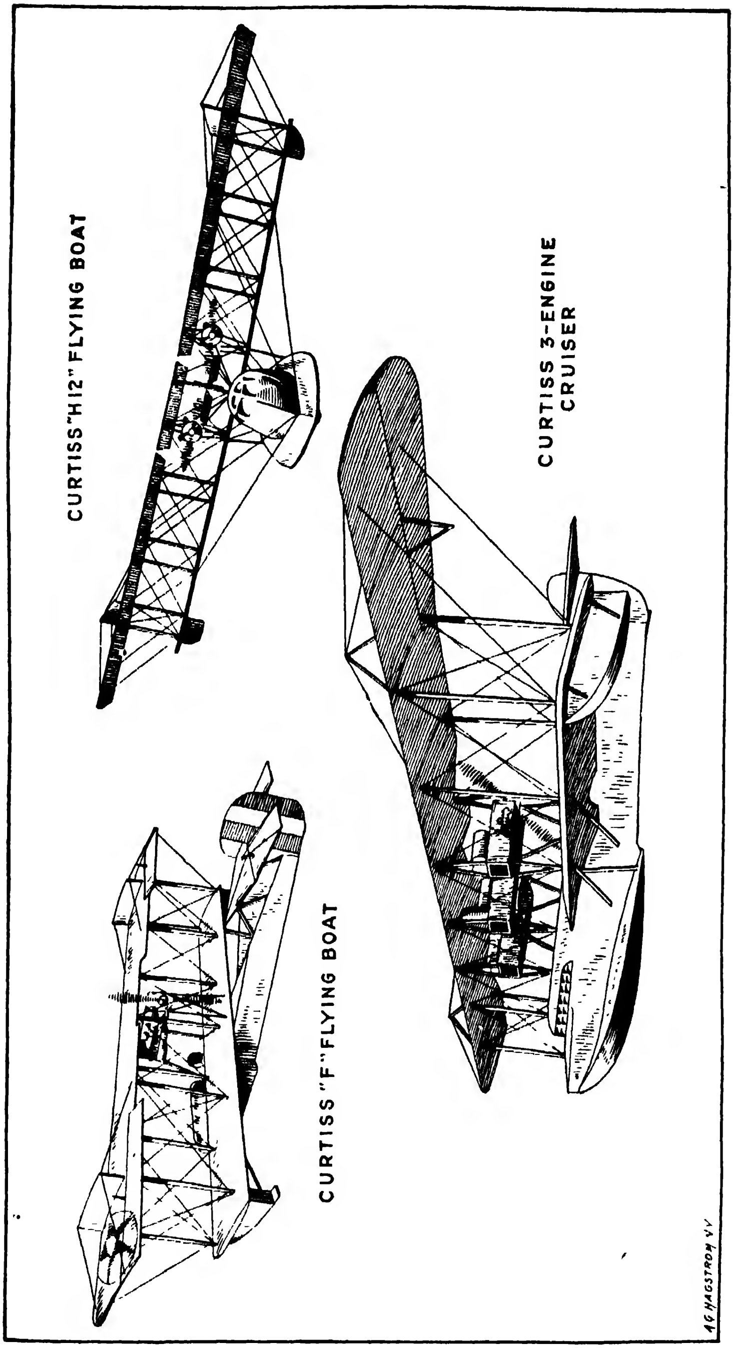


Plate 15.—Types of Curtiss Pre-War Flying Boats Having One, Two and Three Power Plants.

How much power will he require? This he can determine by making a scale model and trying it in the wind tunnel to determine its resistance experimentally and making some calculations with the total weight and proposed speed as a basis. He must supply power enough to raise the weight against the attraction of gravity and this will vary with his desired

rate of climb. Here a time factor enters into consideration. The horsepower then, must be sufficient to overcome both gravity and parasitic resistance and will vary with the time factor. A fast flying airplane or one capable of quickly climbing to its ceiling will need more power than one that is given more time to do the same work.

Then, when he has determined his speed and power, he must decide if his new design will incorporate one engine or more. Here he must take in the factor of reliability. For an airplane with a useful load of a ton,

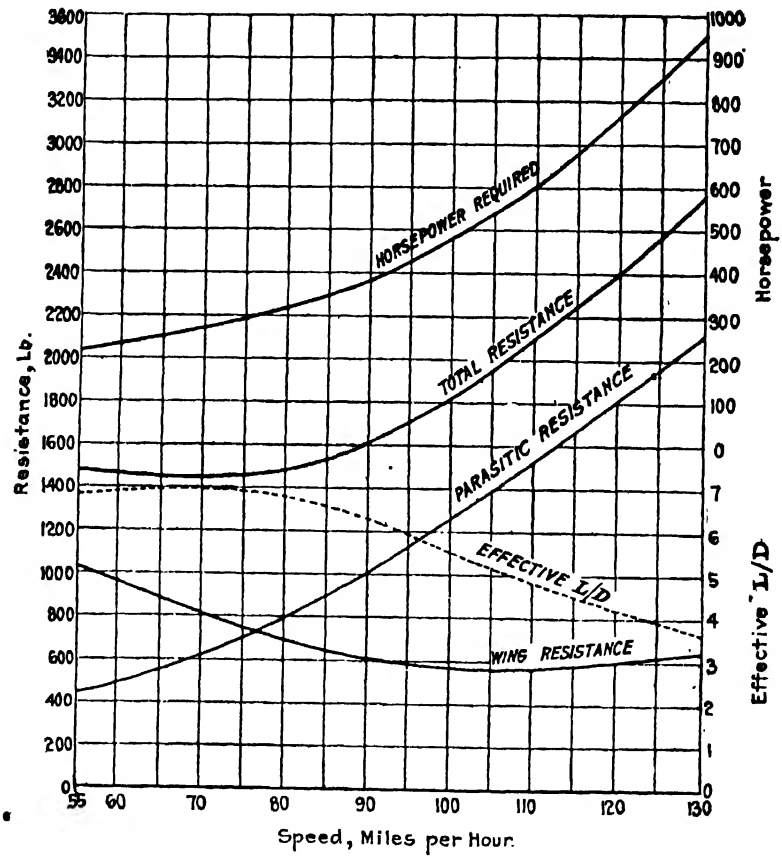
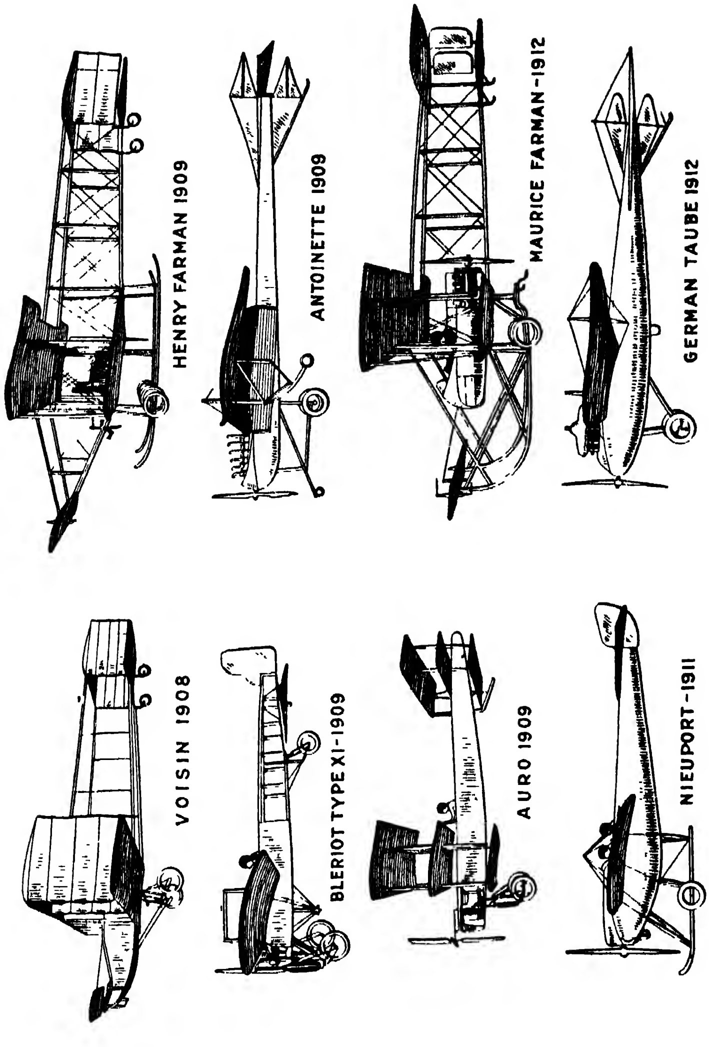


Fig. 21.—How Various Resistance Values and Speeds Affect Amount of Horsepower Required.

he can use one, two or three engines. The larger the number of engines, the less the chance of forced landings due to power plant failure but the more power required because a multi-engine plane is not as efficient aerodynamically as a single engine plane. And so it goes, he must weigh an advantage against a corresponding disadvantage and what appears to be a reasonable compromise to one designer will seem a poor choice to another.

He wants his horsepower loading to be within the bounds of good practice so he finds that a high speed airplane must not exceed 12 pounds gross weight per horsepower while a moderate speed airplane will fly with



—Some Ea Ty of Airplane Made Su ssful Fligh

20 pounds per horsepower. If he used the former value, he will get $\frac{5000}{12} = 600$ horsepower. He can use one engine of that capacity, two 300 horsepower or three 200 horsepower. As he wishes to fly fast, he will decide against multi-engine design and use but a single engine. If satisfied with a lower speed, he finds he can fly with $\frac{5000}{20} = 250$ horsepower. If he uses two engines of 150 horsepower each, he will have an ample reserve of power and can fly with engines throttled and could maintain flight with but one engine if the other failed, but he can also use but one engine if he wishes of the required horsepower thereby reducing reliability.

Power Requirements of Airplanes.—A large factor in the horsepower requirement, particularly at high speeds, is the wing resistance. A second large factor is the fuselage and other parasitic resistance. As landing speed is the criterion for the wing area, two machines of the same weight may be equipped with wings of very different area, the larger area for the lower landing speed. Therefore at the same higher speed, these two machines would exhibit considerably different requirements in horsepower, even if the wing curve were not considered. The converse naturally holds. If two machines have the same wing area but differ in weight, the lighter machine will have the lower landing speed and slightly higher maximum speed. Taking the foregoing into consideration, the designer will design his biplane structure so it will have minimum parasitic resistance, so he can attain good speeds without too much power expenditure. If his plane is to be used for passenger carrying, he will choose an area that will assure moderate landing speeds. The parasitic resistance of an airplane depends upon that of its component groups. Some designs, with many exposed struts and wires will have high resistance. The figures that follow show that there is a wide range of values for the same groups of different airplanes. Horsepower requirements are:

	Per Cent
Panels or Wings	80 to 25
Wing accessories	8 to 25
Landing gear	3 to 17
Tail units	2 to 15
Fuselage	10 to 45

A series of curves, reproduced from the S. A. E. Journal is given at Fig. 21. These were prepared by N. L. Lieberman and show how the various resistance values and speeds affect the amount of horsepower required. For example, an airplane having a total resistance of 2,600 pounds is to fly at 100 miles per hour. We first locate the speed desired on the base of the chart and follow the vertical line up to the point where it intersects the horizontal line extending to the right from the value 2,600 on the left vertical side of the chart. From the point of intersection of these lines to the horsepower values on the right vertical side of the chart, we find that about 500 horsepower will be required. This method of procedure will enable the reader to easily find the horsepower required for any known resistance in the range of the chart. To show how airplanes vary in their power requirements the tabulation at Table III A of various early post war airplanes is presented. This was prepared by Commander J. C. Hunsaker, U. S. N. It will be seen that the wing loading varies from 4.8 pounds per square foot to 12.3 pounds per square foot of wing area. The power loading or pounds per horsepower varies from a minimum of 8.4 pounds to a maximum of 26.1 pounds. Figures are also given showing the percentage of gross weight for the airplane without load; for the structure; for the power plant; for the empennage, and also for the body. The weight of the wings for each square foot of area is also given. The wing loading for the most part ranges between 8 and 10 pounds per square foot. The power loading is for the most part below 20 pounds per horsepower. The ratio of empty plane to gross weight varies from 55.6 per cent which gives the highest

useful load of 44.4 per cent of gross weight to a high value of 79.6 per cent, which means a useful load of only 20.4 per cent. The useful load, for the most part ranges from 30 to 40 per cent in the early types tabulated. This value has been materially improved in latest types, a number of designs having a useful load 50 per cent of the gross weight.

TABLE IIIA

Power Requirements of Early Airplanes.

Name	Gross Weight lb.	Area sq. ft.	Lb. per sq. ft.	Lb per hp.	Percentage of Gross Weight					Unit Weight of Wings lb. per sq. ft.
					Empty	Structure	Power-plant	Wing and tail	Body	
Hanriot	1,709	195	8.7	13.1	65.6	39.0	26.6	15.5	23.5	1.15
Avro Spider	1,734	208	8.3	15.1	66.2	32.4	33.8	15.9	16.5	1.17
Hanriot	1,827	195	9.3	14.0	67.9	43.0	24.9	14.5	28.5	1.15
SE-5A	2,100	240	8.7	11.7	72.9	35.1	37.8	15.7	19.4	1.22
Avro 504K	1,829	330	5.5	16.6	67.3	43.8	23.5	20.1	23.7	
VE-7	1,958	299	6.5	13.0	71.1	35.7	35.7	16.6	19.1	0.98
Sopwith (1½)	2,377	353	6.7	18.2	57.8	37.1	20.7	17.0	20.1	0.95
N-9	2,412	496	4.8	24.1	77.9	53.2	24.7	24.5	28.7	0.97
MF	2,448	401	6.1	24.4	75.6	49.5	26.1	25.3	24.2	1.06
Model 40	2,461	508	4.8	24.6	79.6	54.4	25.2	30.3	24.1	1.27
M 8	2,517	204	12.3	8.4	65.0	30.0	35.0	14.9	15.1	1.30
Aero. 39B	2,543	494	5.1	25.4	77.6	53.3	24.3	23.6	29.7	1.09
Aero. 39A	2,618	494	5.3	26.1	78.0	51.7	26.3	22.9	28.8	1.09
HA	3,805	386	9.8	10.0	70.1	36.9	33.5	12.7	24.2	0.99
R-6	3,964	613	6.4	19.8	77.7	48.5	29.2	22.6	25.9	1.32
HA	3,975	485	8.2	10.5	71.7	39.6	32.1	16.4	23.2	1.14
US D9	4,600	514	9.0	11.5	56.2	26.6	29.6	14.0	12.6	1.13
D-4	5,418	620	8.7	14.3	75.2	15.5	29.7	20.6	24.9	1.59
M-1	5,795	695	8.3	16.1	72.9	48.1	24.5	23.0	25.4	1.63
HS-1L	5,900	653	9.0	16.4	68.9	42.1	26.5	22.3	20.1	1.78
HS 2L	6,373	803	7.9	17.7	66.9	41.9	25.0	23.3	18.6	1.69
HS-3	6,900	831	8.3	19.1	65.9	44.8	21.1	23.9	20.9	1.76
Sperry	6,916	678	10.2	17.3	58.9	37.7	21.2	18.1	19.3	1.60
MBT	10,168	1,080	9.4	12.7	64.0	34.2	29.8	18.7	15.5	1.59
H-16	10,900	1,164	9.4	15.1	67.9	41.9	26.0	21.1	20.5	1.76
Caproni	12,810	1,420	9.0	11.8	60.2	25.7	34.5	14.4	11.3	1.15
F-5-L	13,000	1,397	9.3	18.1	63.6	40.8	22.8	21.4	19.4	1.81
F-3	13,400	1,425	9.4	19.1	59.1	37.2	21.9	20.5	16.7	1.70
F-6-L	13,514	1,397	9.7	18.8	57.1	36.0	21.1	18.4	17.6	1.55
Handley Page	14,374	1,648	8.7	17.9	55.6	34.4	21.2	20.3	14.1	1.66
F-5-L	14,844	1,397	10.6	17.6	62.3	36.4	25.9	19.4	17.0	1.81
NC-2	22,600	2,441	9.3	20.9	60.6	35.5	25.1	20.0	15.5	1.59
NC-4	28,000	2,441	11.5	17.5	57.1	30.5	26.6	16.1	14.4	1.59
Tarrant Tabor	44,862	4,950	9.1	15.0	58.2	37.6	20.6	22.6	15.0	1.93

Standard Definitions
Performance and Conditions of Flight

air speed—The speed of an aircraft relative to the air. Its symbol is V.

controllability—The quality in an airplane which makes it possible for the pilot to change its attitude easily and with the exertion of but little force.

drift—The lateral velocity of an aircraft due to air currents.

drift angle—The horizontal angle between the longitudinal axis of an aircraft and its path relative to the ground.

dynamic factor—The ratio between the load carried by any part of an aircraft when accelerating and the corresponding basic load.

endurance—The maximum length of time an aircraft can remain in the air at a given speed and altitude.

factor of safety—The ratio of the ultimate strength of a member to the maximum probable load in that member in actual use.

flight path—The path of the center of gravity of an aircraft with reference to the earth.

ground speed—The horizontal component of the velocity of an aircraft relative to the earth.

load:

dead—See WEIGHT EMPTY.

full—Weight empty plus useful load. Also called "gross weight."

pay—That part of the useful load from which revenue is derived, viz., passengers and freight.

useful—The crew and passengers, oil and fuel, ballast other than emergency, ordnance, and portable equipment.

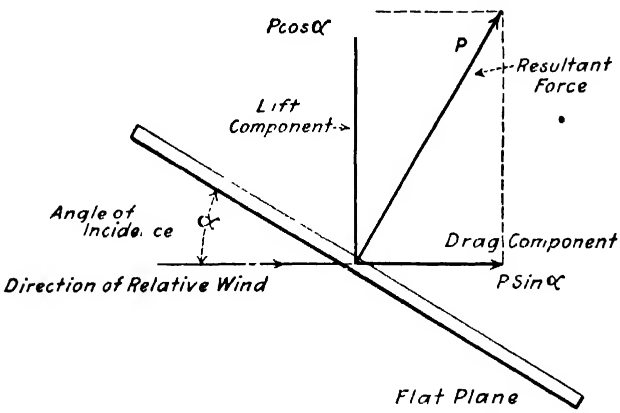


Fig. 22.—Diagram Showing Meaning of Lift and Drag, and Forces Represented by These Teims.

load factor—The ratio of any specified load on a member to the corresponding basic load. Generally applied to the ratio of the breaking load to a basic load.

maneuverability—That quality in an aircraft which makes it possible for the pilot to change its attitude rapidly.

performance testing—The process of determining performance characteristics.

rate of climb—The vertical component of the air speed of an aircraft, i. e., its vertical velocity with reference to the air.

relative wind—The motion of the air with reference to a body, i. e., its motions as observed by a man at rest on the body. The direction and velocity of the relative wind, therefore, are found by adding two vectors, one being the velocity of the air with reference to the earth, the other being equal and opposite to the velocity of the body with reference to the earth.

wash—The disturbance in the air produced by the passage of an airfoil. Also called the "wake" in the general case for any solid body.

weight empty—The structure, power plant, and fixed equipment of an aircraft. Included in this fixed equipment are the water in the radiator and cooling system, all essential instruments and furnishings, fixed electric wiring for lighting, heating, etc. In the case of the aerostat, the amount of ballast which must be carried to assist in making a safe landing must also be included.

QUESTIONS FOR REVIEW

1. Name some early flying machines and give reasons why they did not prove successful.
2. Who made the first practical flights with heavier-than-air craft and when?
3. Describe results of early tests with plane forms and tell who made them.
4. Compare birdflight with airplane flight and outline briefly why birdflight cannot be imitated exactly in man-made mechanisms.
5. How is an airplane balanced in flight?
6. Describe control and balancing elements and their location and functions.
7. Name some general design factors that must be considered in determining best type of airplane.
8. What determines the power requirements of airplanes?
9. What is "relative wind"? Define "factor of safety," "drift," "load factor," "useful load."
10. What is the usual wing loading? What proportion of useful load to gross weight is found in most airplanes?

CHAPTER IV

DESIGN AND CONSTRUCTION OF AEROFOILS

Principle of Dynamic Similarity—How Plane Performance may be Gauged—Meaning of Lift and Drift—Lift-Drift Value for Rectangular Plane—Meaning of Center of Pressure—Center of Pressure Travel—Properties of Cambered Aerofoils—Why Leading Edge Should be Curved Down—Designs of Cambered Aerofoils—Loading of Bird's Wings—Wing Area of Birds—Table IV, Square Feet Wing Area of Insects—Table V, Value of Nature's and Man's Flying Machines—Weights, Speed and Panel Areas of Airplanes—Effects of Wing Loading on Aerofoil Design—Wing Sections Vary in Design—High Lift Wings for Monoplanes—Metal for Wing Structure—Effect of Aerofoil Camber—Effect of Varying Lower Camber—Pressure Distribution on Aerofoils—Inclination or Incidence for Maximum Efficiency—Position of Center of Pressure—What is Meant by Critical Angle or "Burble" Point—Greatest Lift Produced by Upper Surface—Table VI, Percentage of Load Carried by Surfaces—Wing Having Varying Camber or Section—New Aerodynamic Theory—Parasitic and Induced Drag—Table VII, Parasitic Co-efficients of Various Aerofoils—Table VIII, Parasitic Areas of Various Airplanes—Value of Induced Drag—What a Wind Tunnel is—The Curtiss Wind Tunnel.

The reader doubtless wonders how it is possible for an airplane designer to determine the best aerofoil form for a given set of conditions and how it is possible to settle upon a certain cambered surface as the most desirable. The best proportions for supporting surfaces can be obtained by experiments with scale models, which are placed in a wind tunnel and air currents of varying velocities are forced through the tunnels by a large fan or propeller driven by an electric motor or series of motors so its speed can be maintained constant or varied within limits, the air stream flowing around the model to stimulate the air stream travel of a machine in flight.

Principle of Dynamic Similarity.—If the tests are made with a model of correct proportions the action of much larger bodies of identical proportions can be determined with a reasonable degree of accuracy by what is termed the "principle of dynamic similarity." The practical application of this is of great value in both marine architecture and aeronautical engineering. A prediction of the performance to be expected from full size airships may be made after wind tunnel tests of small models. The wind tunnel is a large rectangular section conduit having a large power-driven blower type fan at one end and incorporating suspension and recording devices by which the action of the model can be observed and measured by the experimenter outside of the tunnel. The blower fan can be driven at different speeds and air currents varied to simulate winds of various velocities.

In marine engineering, small models of hulls are drawn through water at varying speeds to determine the resistance of various boat designs, and experiments in the testing basin make it possible to determine how full sized boats will act under similar conditions of speed, so in designing a

seaplane or flying boat, the pontoons or hull must be tested both for hydraulic and atmospheric resistance, this calling for both wind tunnel and basin tests.

How Plane Performance May Be Gauged.—In the cases where the test of a model, which may be either an airplane or any of the parts of which it is composed, is made in the air stream of the same velocity in which the full sized machine or part is to move, the forces upon the small and full sized bodies will be proportional to the square of their corresponding dimensions and also to the square of their relative velocities if the air stream acting on the model is less than the wind pressure that will act on the full sized

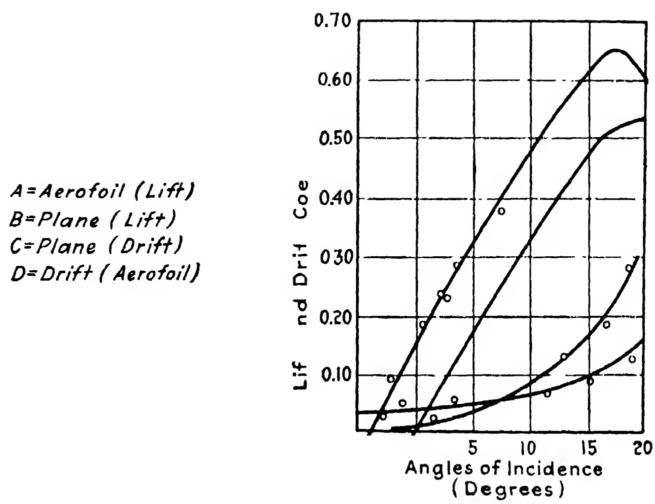


Fig. 23.—Diagram Showing Lift and Drift Values for Flat and Cambered Planes.

body. By blowing smoke in the wind tunnel, the actual flow lines of the air around the body may be determined visually and, if photographed, made a matter of permanent record. In this way, the effect of varying proportions of streamline bodies can be found and the best form for a given duty determined. A scale model of a complete airplane or airship may be tested or any of the structural elements may be tried for resistance or lift.

Meaning of Lift and Drift.—Considering first a flat plane, when this is tipped so it makes an acute angle with the relative wind, it will be subjected to the forces shown at Fig. 22. The vertical force which is P cosine angle of inclination is called the "lift" component, and the horizontal force, which is indicated as P sine angle of inclination is termed the "drag" or "drift" and offers a resistance to forward movement of the plane. The pressure P is a resultant of the two component forces. Obviously, it will be desirable and necessary to have the "lift" component greater than the "drift" or "drag" component and the greater the difference between the two, the more effective the lifting ability of the plane becomes, because the lift is increased and the resistance to forward motion or "drift" is reduced.

The value of the "lift-drift" ratio for an inclined plane will depend upon the inclination and aspect ratio of the plane, the latter not influencing this much above aspect ratios of 8 or 10. Aspect ratio means the relation between the length and breadth of the aerofoil. For instance, a rectangular plane with a length of 20 feet and a breadth of 4 feet would have an aspect ratio of five.

Lift-Drift Value for Rectangular Plane.—The results of a wind tunnel test to determine the lift-drift values for different angles of inclination upon a rectangular plane scaling 12.5 inches advancing edge by 2.5 inches chord are shown graphically in Fig. 23. The wind velocity was 20 miles per

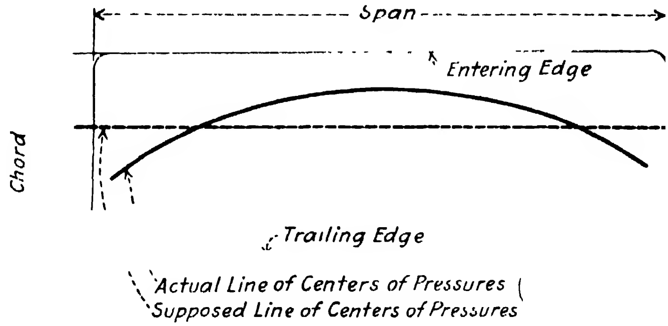


Fig. 24.—Location of Centers of Pressure on a Rectangular Aerofoil.

hour. The lift force follows a linear law of variation up to an angle of about 15 degrees and the lift reaches its maximum value at about 20 degrees. The "drift" coefficient varies slightly between 0 and 4 degrees, from which point it increases rapidly following a parabolic curve. If these curves are compared with similar values for a cambered aerofoil plotted in the same chart, we find that the lift curve of the aerofoil reaches its maximum at about 16 to 17 degrees angle of incidence, after which the lift falls sharply. This angle is termed the critical angle or "burble point" and is the maximum angle of incidence for the aerofoil in question because any further increase decreases the "lift" and greatly augments the "drift," and as these curves tend to meet, the lifting ability of the aerofoil diminishes. Other things being equal, the airplane designer uses wing curves that will have as high lift as possible and as low drift as possible. This ratio varies with various types of aerofoils, depending mainly upon the camber of upper and lower surfaces and the angle of attack or incidence of the wings.

Meaning of Center of Pressure.—The "center of pressure" of any aerofoil or body exposed to the wind may be considered as the point where the resultant force shown at Fig. 22 acts. In the case of a flat plane normal to the wind direction the geometrical center may also be considered the center of pressure. The "center of pressure" position is an important consideration in aerofoil design because the computations for the strength of

wing parts are of necessity based on the position of the center of pressure which represents the load. The initial center of pressure movement is greatest in aerofoils of large aspect ratio, and in flat, rectangular planes, the center of pressure will be at the center of the aerofoil at 90 degree inclination. It does not follow, however, that the center of pressures of all the aerofoil sections will be the same distance from the leading edge. In fact the C.P. of the central part of the plane is nearer the leading edge, while the C.P.'s of the portions near the extremities are nearer the trailing edge. This is clearly shown in Fig. 24.

Center of Pressure Travel.—The travel of the center of pressure is greatest for small inclinations, and it is nearest the leading edge where plane is tilted at small angles of incidence. The reason the center of pressure is nearer the trailing edge as it nears the extremities of the plane is

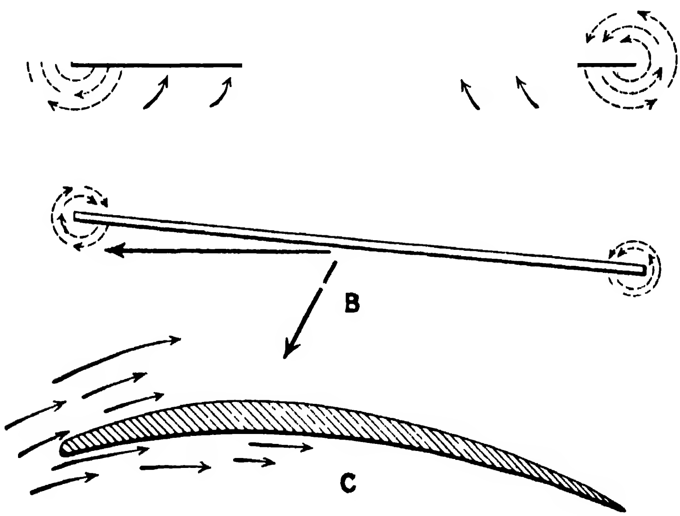


Fig. 25.—Diagrams Showing Advantages of Cambered Section Aerofoil.

because of "end losses." This is caused by the ingress of air at atmosphere pressure into the region of partial vacuum above and also because of the flowing of the air under pressure below the plane into the air not acted upon by the plane movement. This results in a reduction of "lift" and an increase in "drag" for the sections near the wing or plane tips.

Properties of Cambered Aerofoils.—While previous consideration has been of flat planes, it is necessary to consider the cambered aerofoils ordinarily used in airplanes as these have properties that make them much more suitable for sustentation than flat planes. The wings of birds are really curved or cambered in section and unless there was some aerodynamical or structural advantage in this method of forming wings, it is evident that Nature would have used the simpler flat plane. Both theory and practice indicate that there are marked advantages in having airplane supporting

members of cambered section. Comparison of the action of air currents when meeting flat and cambered planes may be made by referring to diagrams at Fig. 25.

Considering the flat plane shown at A, which is supposed to be dropped vertically, it will be evident that owing to the compression below the plane and the rarefaction of the air above it that there is bound to be a circulation of air from below the plane to the less dense area above it, this giving rise to a kind of vortex motion. Then consider the action of the flat plane moving in a horizontal direction as shown at B. Here, also, we will have a vortex action and the leading edge of the plane will meet air having a relative upward velocity and the leading edge cannot meet the air in the most efficient manner as there will be considerable shock and resistance to forward motion. The "drift" curve is of lower value for a cambered aerofoil than it is for a plane as shown graphically in Fig. 20.

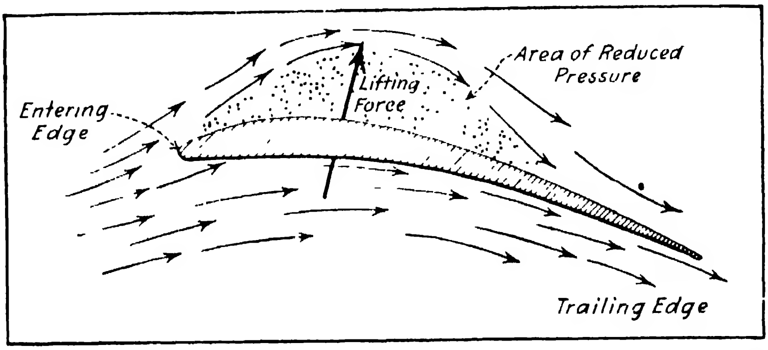


Fig. 26.—Diagram Showing how Vertical Lift is Obtained on Cambered Aerofoil Because of Air Pressure.

Leading Edge Should Be Curved Down.—To meet the air without shock it is important that the leading edge be curved down so it will approximate the direction of the air currents meeting it as shown at Fig. 25 C, and the shape of the aerofoil be such that it can be considered as an element of a body of good streamline form. As will be seen by reference to Fig. 26, the air stream travel is such that it is at first upwards, then finally downward, so in the case where the aerofoil is moving horizontally and inclined at a moderate angle of incidence having a low "drag" or "drift" value to retard its forward movement, that a downward momentum will be given to the air streams, this resulting in a vertical lift.

Designs of Cambered Aerofoils.—The air streams flowing over the top of the aerofoil are deflected sharply upwards and as a result, there is an area of reduced pressure above the top camber of the aerofoil which augments the value of the lifting force by reducing the pressure of the air above it and consequently the resistance to the upward movement of the aerofoil. The real advantage of a cambered aerofoil evidently is that it receives a current of air in an upward direction and directs it downward, thus obtaining a lift reaction. The best design of cambered aerofoil would be the form that had the greatest area of negative pressure on top and

the greatest value of positive pressure on the bottom and that at the same time was so formed that there would be no break or eddy in the streamline air flow over its surfaces.

Loading of Bird's Wings.—In the preceding chapter mention was made of the similarity in cross-section of some of the aerofoils used for airplane support and the wings of birds. The wing loading of birds, i.e., the amount of weight carried per unit area is light compared to that of flying machines as it varies from half a pound to 2 pounds per square foot. The wings

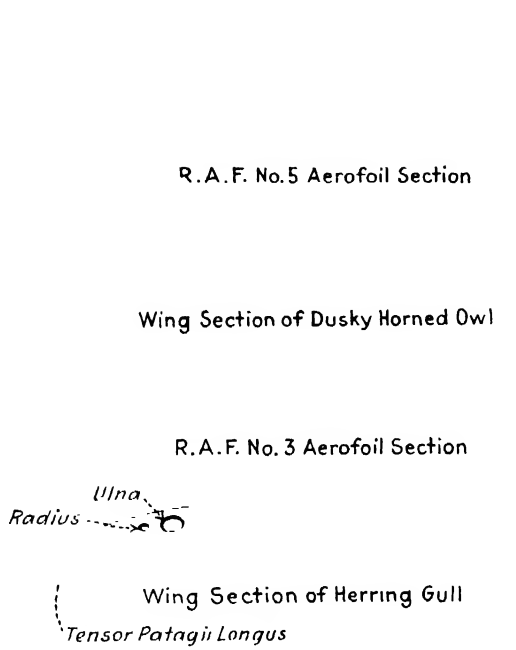


Fig. 27.—How Bird's Wing Section Compares with Aerofoil Sections.

of a black vulture, for instance, are loaded 1.25 pound per square foot. The sustaining members of the dusky horned owl and the tawny eagle are loaded about 0.90 pounds per square foot. All birds' wing sections are different and undoubtedly have changed in form as a result of a natural development or evolution depending upon the habits of the birds, such as whether they were gliders, soarers, flappers or swimmers.

Wing Area of Birds.—The student of airplanes may wonder what the proportions of the flying machine devised by nature are and how the supporting surfaces compare in different birds in reference to their weight and flying power. It is conceded that while a study of bird flight and form may be of interest to the student, it is hardly necessary to give this more than passing consideration at the present time because airplane design is influenced very little by the study of the flight of birds. It has been stated that in pre-historic times much larger creatures inhabited this earth than we know of today. These included peculiar flying forms that were neither bird, reptile or mammal, but which had characteristics of all these.

Many centuries ago a large flying creature which was a combination of reptile and bird and which was known as the Pterodactyl existed, and while it is not possible to give the exact size of this creature, from the present existing skeletons reconstructed by modern scientists, it is assumed that the wing spread was about 20 feet and that a supporting area of about 25 square feet was available for supporting it in flight. The weight was 30 pounds and it was estimated that it was capable of exerting about 1/25 H.P.

If we consider the modern birds, perhaps the largest soaring biped is the condor, which has a wing stretch of 10 feet from tip to tip, a weight of 17 pounds, a wing area of about 10 square feet and which is capable of exerting about 1/30 H.P. The turkey buzzard is a smaller soaring bird which has a wing stretch of 6 feet, a supporting area of 5 square feet, a weight of 5 pounds and a power capacity of but little over 1/100 H.P. It will be evident that the ratio of supporting surface to the weight of the creatures does not always vary directly with their weight and, strange to say, the larger the creature the less relative power and surface area is needed for its support. It has been stated that the lungs of a bird, filled with air and the fact that all of its major bones have very light walls and are hollow greatly reduced the body weight in proportion to its size and its form was such that a certain aerodynamic lift was obtained by air pressure under the body while in flight. Then again, much of a bird's bulk is due to feathers, which are light in proportion to their size. When plucked, a large bird shrinks in size in an amazing manner. Feathers are nearly as light as air they displace and even quills are picked up by the wind and carried away because of their light weight in proportion to their size.

The following table, which deals with insects, is given to support this contention. In this, as a basis of comparison, each insect is supposed to be proportioned so that it will weigh 1 pound. Insects fly by very rapid vibration of their wings and seldom soar though exceptions should be noted in the case of the butterfly and dragonfly which soar for brief periods. Insects having a high wing loading must keep their membranous supporting structures in rapid beat if they are in the air. The figures given were published as early as 1868.

TABLE IV

Square Feet Wing Area per Pound Weight

Insects	Wing Area
Gnat	49.0
Dragon Fly	30.0
Bee	5.25
Flies	5.1
Stag-Beetle	3.75
Rhinocerous-Beetle	3.14

This table serves to prove the law that the larger the creature the less the relative area of support to a given weight holds true as applies to insects, and as we shall demonstrate by the following table, which has been prepared from data on birds compiled by Langley, which has reference

TABLE V

Value of Nature's and Man's Flying Machines

Birds	Weight in Lbs.	Surface In Sq. Ft.	H.P.	Area per Lb.	H. P. per Lb.	Lbs. per Sq. Ft. of Surface
Humming bird	0.015	0.026	0.001	1.73	0.066	
Pigeon	1.00	0.7	0.012	0.7	0.012	
Wild goose ...	9.00	2.65	0.026	0.2833	0.00288	
Buzzard	5.00	5.3	0.015	1.06	0.003	
Condor	17.00	9.85	0.043	0.57	0.0025	
Pterodactyl ...	30.00	25.00	0.036	0.833	0.0012	
Airplanes						
Bleriot XI (early monoplane)	700.00	150.00	25.00	0.214	0.035	4.7
Wright (early biplane)	1,100.00	538.00	25.00	0.489	0.022	2.04
Curtiss (early biplane)......	700.00	258.00	60.00	0.368	0.85	2.7
Standard Model J (obsolescent)	1,350.00	429.00	100.00	0.318	0.014	3.1
Wright-Martin Model V (obsolescent)	1,725.00	430.00	150.00	0.24	0.092	4.01
Burgess Type V Seaplane (obsolescent)	1,800.00	500.00	100.00	0.27	0.55	3.6

Note—Airplane weights given without passengers or military loads.

to both soaring birds and those which fly by flapping their wings it will be evident that the law mentioned holds true for large living creatures. Birds, such as the pigeon and goose, seldom soar, and they must keep flapping their wings practically all the time they are in flight. The humming bird flies by moving its wings so rapidly so that its flight resembles that of an insect more than it does of a bird. The larger creatures enumerated are soaring birds and it is to these that the aeroplanes should be compared; and only when the bird is soaring with its wings practically motionless. The figures given are only approximate, but are of interest in showing the proportions obtained in both natural and man-made flying machines. A table showing the weights, speed and panel areas of more modern types of airplanes is appended, the machines being designated by number for identification. However, these airplanes are relatively slow speed types and higher speeds are now possible.

Effect of Wing Loading on Aerofoil Design.—The wing loading of early airplanes was seldom more than 3 pounds per square foot and in the case of the early Wright machine it was little more than 2 pounds per square foot. At the present time wing loading has increased to 5 or 6 pounds per square foot average and in some very high-powered fast airplanes it may run up to 10 or more pounds in rare instances. A wing section

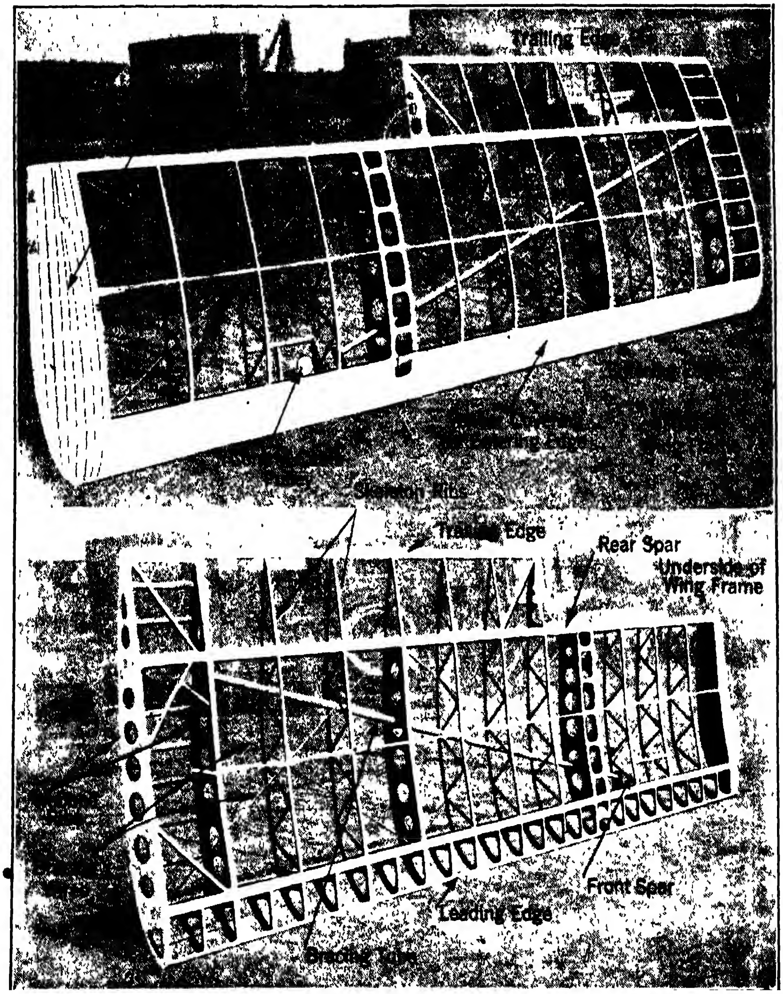


Fig. 28.—Skeleton Structure of Pitcairn Fleetwing Aerofoil Showing Cambered Ribs which Give the Wing its Shape. A—Wing Structure Viewed from the Top, Note Cut-out for Aileron. B—Wing Structure as it Appears from the Bottom.

to carry a heavy load must be a deep section. The section shown at Fig. 29 gives the approximate proportions of the early Wright aerofoil which was lightly loaded, and its shallowness will be apparent. The diagram at Fig. 30 shows the deeper section needed for structural strength and to accommodate spars of the proper cross-section to withstand the increased load

when the aerofoil is used in a biplane structure. When used in a monoplane, the section is even deeper than that shown, this depth depending on the method of wing bracing. Internally braced cantilever wing monoplanes are of deeper section than wings having external bracing. A modern, high speed single seater, the Wright Apache with biplane aerofoil structure is shown at Fig. 31 and a well designed cabin monoplane with externally braced aerofoil is shown at Fig. 32 for purposes of comparison.

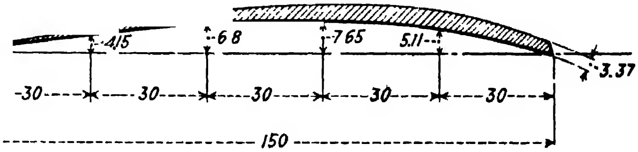


Fig. 29.—Aerofoil Section of Early Form Suitable for Light Loading.

It will be evident, therefore, that structural strength, as well as aerodynamical considerations, must be taken into account in selecting aerofoil sections. The factor of strength must be considered fully as much as efficiency, and if a compromise design must be evolved where one or the other of these qualities must be sacrificed, it is better to favor strength even if the efficiency is somewhat less. Many forms of wing sections have been developed. Some have attained one object, others have properties that make them suitable for other work.

There is no one wing section that is best. Efficient forms devised for speed craft are not suited for slow flying or weight carrying planes. The

DATA ON WEIGHTS, SPEED AND PANEL AREAS OF AIRPLANES

Machine		Gross Weight, Lb.	Gross Panel Area, Sq. Ft.	Speed Range, Miles Per Hr.		Parts, Percentage of Total Weight					
No.	Type			Low	High	Panels	Panel Accessories	Landing Gear	Fuselage	Tail	Wing Curve No.
3	2	2,100	352.0	50	95	14.35	4.87	3.43	75.0	2.41	Eiffel No. 36
4	2	2,400	352.0	50	95	12.55	4.20	3.00	78.1	2.11	Eiffel No. 36
5	3	2,750	416.0	55	125	11.50	2.07	5.15	78.8	2.16	R.A.F. No. 15
6	3	3,650	416.0	55	125	8.66	1.56	4.11	84.0	1.63	R.A.F. No. 15
7	4	3,650	505.0	55	105	11.40	2.74	4.60	79.6	1.67	R.A.F. No. 6
8	4	4,300	505.0	55	105	9.66	2.33	3.91	82.5	1.41	R.A.F. No. 6
1	1	1,800	246.0	55	125	10.30	2.78	5.00	79.8	2.00	R.A.F. No. 15
2	1	2,050	246.0	55	125	9.06	2.44	4.39	82.2	1.76	R.A.F. No. 15
9	2	2,100	280.0	50	110	9.33	3.10	4.56	80.2	2.52	R.A.F. No. 15

best aerofoil section to use depends entirely upon the use to which it is to be put. Any fixed aerofoil section is suited to only a limited range of flying angles, and the present construction of a tilted aerofoil of fixed cross-section is by no means the best, if one looks at it from a theoretical point

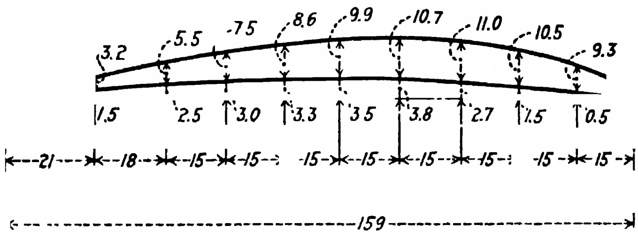


Fig. 30.—Aerofoil Section of Modern Airplane Suitable for Heavy Loading.

of view, though it is a compromise that gives adequate results in practice. To secure the best results from an aerofoil as regard lift, drift or resistance and center of pressure position, the section of the aerofoil should be changed with every alteration of flying speed and even for different parts

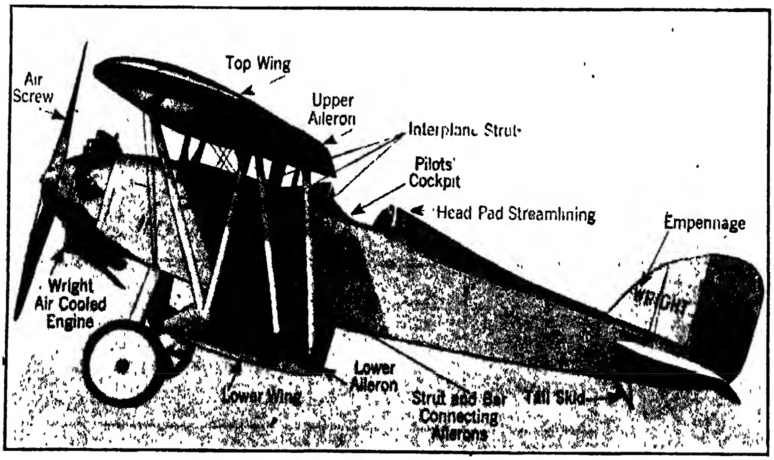


Fig. 31.—Wright-Apache Pursuit Biplane, a Modern Military Type Equipped with Air-cooled Engine. Note Relatively Thin Wings and Interplane Struts.

of the structure because the center of pressure position is different at various points along the span. This is a theoretical consideration that is not always possible to meet in practice, owing to structural difficulties. Inasmuch as a practical variable camber wing has not yet been designed, the fixed aerofoil section to be selected depends upon the type of plane and the work it is expected to do, and the modern designer has a wide range to choose from.

Wing Sections Vary in Design.—Various wing sections of early thin wing forms intended for widely differing types of machines are shown at Fig. 33. That at A is intended for a fast scout plane and while the section is a good streamline form, the lift is so small at moderate speeds that it

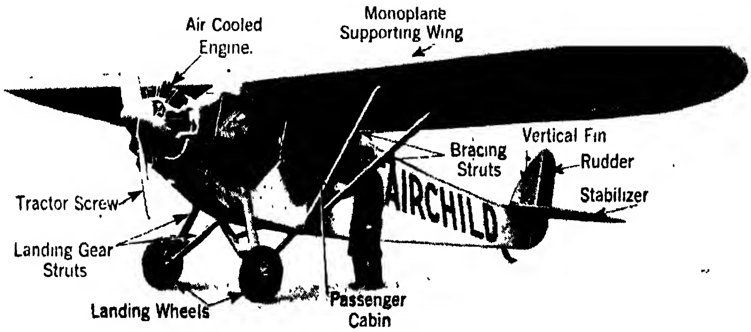


Fig. 32.—Fairchild Sedan Monoplane for Photographic Work and Passenger Carrying, a Late Design of Small Commercial Airplane, Using Radial Cylinder Air-cooled Engine and Metal Propeller. Note High Lift Thick Wing, with Pronounced Overhang.

can be used only on very fast flying planes. The same applies to the aerofoil shown at B, which has a reverse curvature at the trailing edge. This wing has good aerodynamical properties because the center of pressure travel is small, but as its lifting power is low compared to the sections shown at C and D, can be used to advantage only on speedy machines. The modern forms of high speed planes have double cambered aerofoils such as shown at Fig. 44. Such aerofoils permit of speeds of over 200 miles per hour when fitted to seaplanes and 250 miles per hour maximum on a high-powered land plane of similar design. Wings of the forms shown at C and D are used on medium speed biplanes. The landing speed of a small plane having wings of the section shown at A and B would be about 60 miles per hour, and would call for very skilful piloting. They would permit a maximum speed of about 120 miles per hour. The other wing sections at C and D are suited for medium speed biplanes, as they would permit a landing speed of about 40 miles per hour. The maximum speed of a properly powered plane using wing sections A or B may attain values of over 120 miles per hour, that of sections C and D would not be much more than 80 or 90 miles per hour.

In order to illustrate how widely the requirements differ and the types of aerofoils best adapted for use under different conditions of airplane operation, the sections at Fig. 34 are given. These are reproduced from A. W. Judge's treatise, "The Properties of Aerofoils and Aerodynamic Bodies," and show practical biplane wing sections of early development.

The wing form required to secure the highest lift with the most efficiency is shown at A. Such an aerofoil would be suitable only for a low-speed machine, as it would offer a high head resistance even at small angles of incidence. It would be a good form for slow flying machines but very inefficient for high-speed types. The section at B is typical of aerofoils

intended for medium flying speeds and at the same time secure a fairly low landing speed. An aerofoil of this type could be utilized for a machine having a flying range between 35 and 65 miles per hour. The wing at C shows a section developed to obtain a high lift-drift ratio at small angles of incidence, and while a machine equipped with aerofoils of this

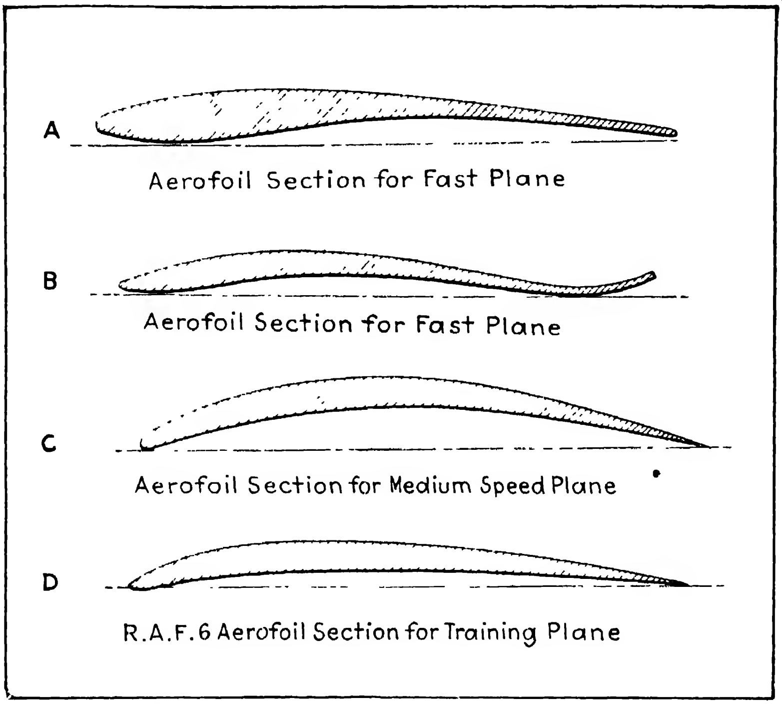


Fig. 33.—A and B, Early Aerofoil Sections for Fast Planes. C, Aerofoil Section for Medium Speed Plane. D, R. A. F. 6 Aerofoil Section for Training Plane.

section would not have a very low alighting speed, it could attain fairly high flying speeds as the range would be from 55 to 100 miles per hour. The wing section at D is a peculiar aerofoil designed for very high speeds. It would be entirely unsuited for low-speed work and is to be used only on machines of very high power. The landing speed would be very high as the angle of incidence is negligible in normal flight.

High Lift Wings for Monoplanes.—The development in the use of all metal wing structures and the solving of structural problems by the use of duralumin, an aluminum alloy that has the tensile strength of mild steel and that can be heat treated to increase its physical properties as steel can, to a degree, and which weighs about one-third as much as steel has made possible the construction of wing sections of great strength and light weight and of deep section. The light weight and limited performance of the early Wright and Curtiss biplanes, which were built of spruce and bamboo, covered with cotton sheeting and held together by stove bolts and bracing of piano wire were clearly the result of the limitations imposed by the structural materials at hand. Even most of the Allied war planes were

built of spruce and ash and cloth, though there was some refinement of detail by the use of alloy steel tubes and bolts and fittings in the structure and some slight saving in weight due to their use. The Germans, who had worked duralumin and magnesium-aluminum alloys into the framework of their Zeppelin rigid dirigibles had developed a technique in the application of light metals to aircraft structures that permitted them to build all

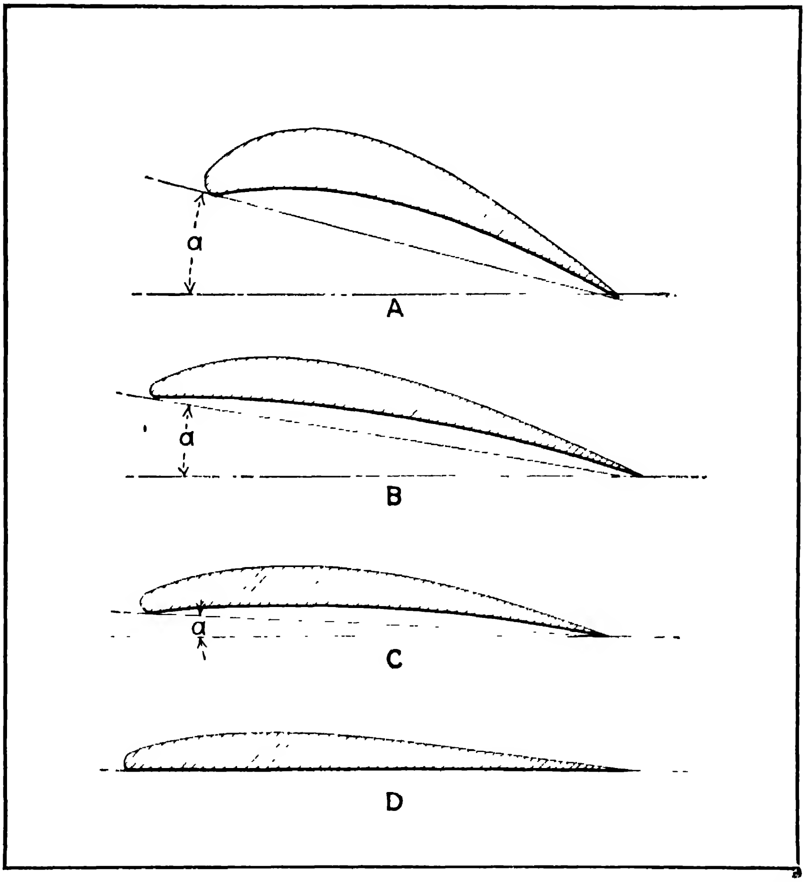
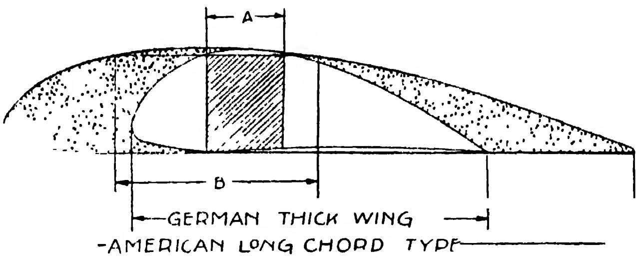


Fig. 34.—Early Aerofoil Sections Designed for Special Work, Showing how Widely They Differ.

metal airplanes that had good performance and that were light and strong. Monoplanes were built by Junkers that had no external bracing and which showed very good aerodynamical properties because of the reduction of parasitic resistance. The deep section or thick wings made it possible to use bridge truss construction of the cantilever type for the spars and all loads could be adequately resisted by internal bracing that offered only gravity resistance to flight and no parasitic resistance. After the war, much of this technique became available to other designers and the Germans no longer had a virtual monopoly over the design factors affecting heavy lift, deep section, all metal aerofoils.

One of the pioneer experimenters with high lift wings in this country was William B. Stout and he proposed an airplane nearly ten years ago that would be practically all wing, the fuselage and even power plant being incorporated in a deep section aerofoil. This was based on his idea that "the eventual airplane will expose no parts to the air that do not give back lift in return for their resistance." When one considers that approximately two-thirds of the total power required to overcome the gross resistance to flight is needed to overcome parasitic resistance, it will be evident that his reasoning was based on sound premises.



—COMPARISON OF THE GERMAN THICK-WING AND THE AMERICAN LONG-CHORD TYPES

Fig. 35.—Comparison of German Thick Wing and American Long Chord Type.

In a paper read before the Society of Automotive Engineers, Mr. Stout discussed the problems of thick wing design in a very informative manner. He stated:

"The entire problem in a thick-wing job seems to be not so much the strength of the spar members involved, as this is comparatively easy to obtain, but the *wing rigidity* so that there is no distortion or warping of the wing against aileron action, nor change of angle of incidence at the tips at different angles of attack of the plane. Foreign designers, particularly of the German school, have gone either to the thick-wing curves, such as the Junker, or to outside trussing, such as the Dornier. In the thick-wing Junker type, with an almost rectangular span of wing, the airfoil becomes so very deep at the fuselage in proportion to the chord of the wing that considerable speed is sacrificed to structural depth. To get the twist out of the wing, it is necessary to use very long interlatticed spars of more or less tetrahedral connection. This binds the structure into a solid unit but adds considerable weight, although, in the metal Junker, the wing is about the same weight per square foot as wood-and-cloth wings of the same general factor of safety and maximum spread.

In the Stout type of wing we used a much more tapered plan view, so that for equal spar depth at the center section, as shown in Fig. 35, we had a wing of much better fineness ratio for high-speed work, at the same time the amount of structural space in the thick-wing, or German type of wing, extended only as far as the shaded portion A whereas, in our long-chord type, our structural space was almost three times the volume, as at B, allow-

ing considerable advantage particularly for wing-tip rigidity. It was possible to build larger areas of equal weight by this method. The advantage of getting the greater amount of area toward the fuselage is obvious, from both structural and aerodynamic standpoints.

Metal for Wing Structure.—It is true that steels can be had of much higher tensile-strength per pound than dural, as duralumin has come to be called colloquially. It is also true, however, that these steels, heat-treated in very thin sections, are even more of an unknown quantity due to inaccuracies in the heat-treating, particularly in experimental structures, and

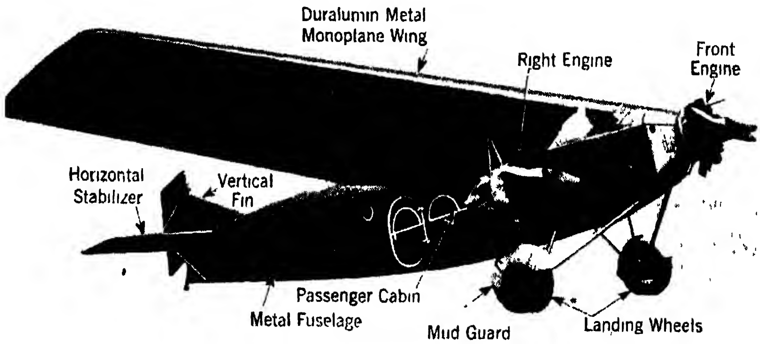


Fig. 36.—Ford-Stout Tri-Motored All-Metal Transport Plane, a Recent Commercial Design for Carrying Freight or Passengers. Note Tapering Thick Section Cantilever Monoplane Wing and Absence of Bracing Struts or Wires.

therefore have variable physical characteristics. Dural, treated in a bath of nitrates at temperatures well under control and fabricated quickly before the tempering has begun to take effect, is thoroughly reliable and can be depended upon for a 55,000-pound per square inch tensile-strength, with an 18-per cent elongation. If steel spars are used in connection with dural structure, provision must be made for differences in the coefficient of expansion and for the production difficulties of riveting metals of different hardness."

The following prediction regarding all metal construction for aircraft was made about five years ago (1922) by Mr. Stout and that it is becoming more and more true as time goes on is evident to the student familiar with late airplane development. "It cannot be expected that the first metal-construction attempts of any manufacurer will be a success in every particular but, if America is to lead in aircraft, it must lead in metal aircraft, as it is my opinion that, in a comparatively few years from now, wooden airplanes in the air will be scarcer than wooden ships on the sea, and that all airplanes flying under insurance rulings will be of all-metal construction.

Thick-wing airplanes are developing fast, both in monoplane and biplane types. Retractable chassis, wing-type radiators and all those items that the recent Pulitzer events have shown to be practicable, will appear

shortly in commercial airplanes and increase their profit-paying possibilities. But if safety and low cost are to come with these items of greater performance, then must metal construction and production methods be applied to the producing of an airplane for American air-services that shall be safe, cheap, economical and long-lived.

All metal planes, to date, can be called experimental. The future commercial airplane, however, will undoubtedly be an all-metal construction. Metal planes mean greater safety to pilot and cargo; a possibility of considerably lighter weight; less production cost, particularly as quantities go up and the demand increases; and easier servicing and simple repairs provided the airplanes are designed with this idea in view."

One of the latest types of all metal airplanes developed by Mr. Stout and built by the Ford Motor Company is shown at Fig. 36. It is a deep section monoplane and is powered with three 200 horsepower Wright motors of the radial air-cooled type.

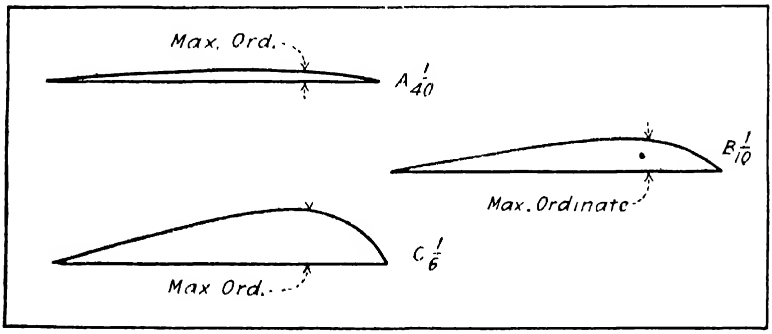


Fig. 37.—Wing Sections Experimented with to Determine Value of Top Camber.

Effect of Aerofoil Camber.—Both upper and lower cambers of an aerofoil have material influence on the aerodynamical properties. Very complete experiments have been made to determine both the upper and lower cambers, and considerable data is available for the student. It is not within the province of a discussion of this character to go deeply into the theory of form and proportions, but it may interest the reader to consider typical designs in both cases and study the values determined for each form. For example, a range of sizes of which the forms shown at Fig. 37 are examples were tested, all having a flat lower surface but with upper surfaces of varying convexity and depth of section. The figures in the illustration show the proportions the maximum ordinate bears to the chord. The position of the maximum ordinate was the same in each case, or about 0.292 of the chord from the leading edge. It is found that the thicker the aerofoil the greater the lift coefficient at small angles of incidence. This is undoubtedly due to a greater total deflection of the air. The thin aerofoil at A starts to lift at minus 1 degree of incidence, but the thick section at C starts to lift at minus 7 degrees angle. At 0 degrees angle of incidence the values of the lift coefficient are proportional to the depth of sections. The section best adapted for a wing for average flying is one that has a top camber that

is an average between the form shown at A and B, the depth of the camber being about 1/20 the chord length. The camber shown at C is used only in propellers and in thick wing monoplane aerofoils and then only where strength is desired, as near the hub of the air screw or at the point of attachment of the wing and the fuselage when the cantilever principle is employed for wing support with internal bracing. It would have too much resistance to be used for a wing section throughout the length or span of the aerofoil.

Effect of Varying Lower Camber.—In order to determine the influence of various lower cambers, a series of aerofoils were made with various degrees of concavity. A series of tests were made with four aerofoils having sections as outlined at Fig. 38. The deduction that can be made from

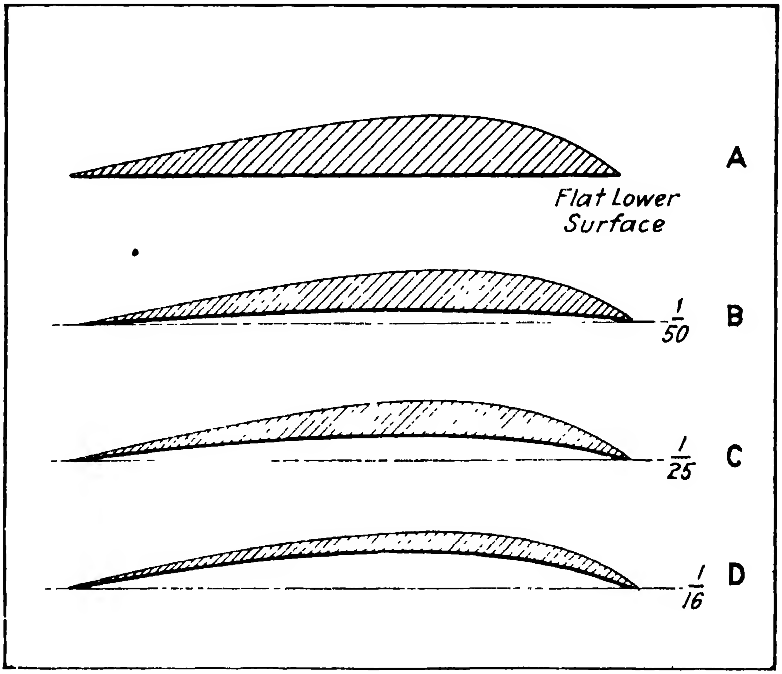


Fig. 38.—Wing Sections Experimented with to Determine Value of Various Bottom Cambers.

the data shows that the under-camber influence is to increase the lift at all angles and even at small angles the percentage increase is considerable. The form at D has the greatest lift coefficient value. At zero angle of incidence the form at B has 13.9 per cent increase over A; C has 24.2 per cent, and D has 33.3 per cent increase over the form with the flat under-surface. The upper camber was the same in all cases. At 6 degrees angle of incidence the percentage increase varies as follows: B, 4.9 per cent; C, 8.2 per cent; D, 12.9 per cent. At 10 degrees angle of incidence the form at B has 2.8 per cent increase; C, 7.3 per cent increase, and D, 11.2 per cent increase.

It is therefore evident that the best form for securing maximum lift at

low speed will have both upper and lower surface cambers pronounced. A sharp leading edge is not as good as a slightly rounding one. The wing sections of birds show a fine tail angle and have considerable under camber as well as a pronounced upper camber and a rounded entering edge. It is possible to obtain 10 to 15 per cent more lift at high angles of incidence by using a fine tail angle and a good under camber. For high-speed biplane work it is evident that aerofoils having a good upper camber but a nearly flat lower camber or forms having two convex surfaces as shown at Fig. 34, C and D will be most suitable.

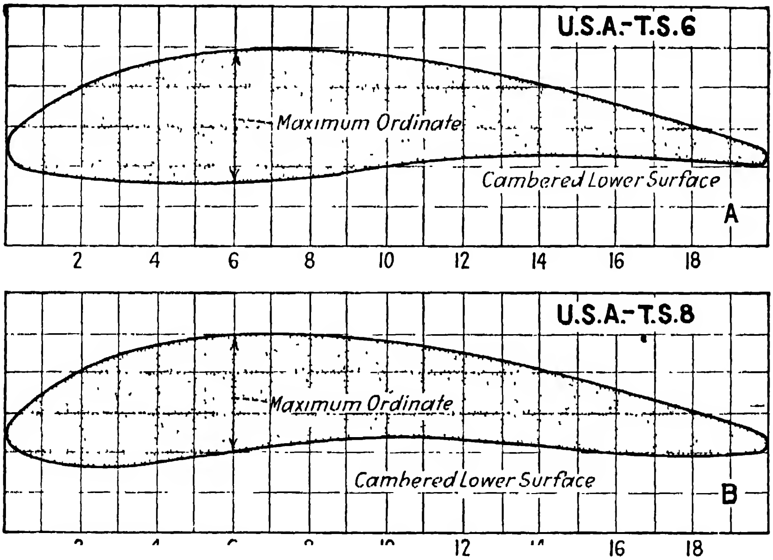


Fig. 39.—Two Efficient U. S. Army Thick Wing Sections with Curved or Cambered Lower Surfaces.

In considering changes in the lower surface of modern thick wing sections, it is found that the L/D is a maximum when the lower surface is nearly flat and decreases in value if the camber is moved much either way. The lift is increased at all angles of incidence by raising the lower surface. The minimum drag comes at lower angles with thicker sections. Sections with a thick leading edge and thin trailing edge give a low drag and high lift at all angles. The maximum lift is greatest when the maximum ordinate is 0.160 of the chord and a slight variation either side decreases the lift appreciably. The maximum ordinate must be kept very closely at 1/3 (one-third) of the chord from the leading edge or the maximum lift will be reduced materially. The wing sections shown at Fig. 39 have a value of 12.9 L/D and are efficient wing sections of that type. Those shown at Fig. 40 have a value of 13.2 for the Durand 13 and 12.3 for the U. S. A. T. S. 9.

The general conclusions to be drawn from a series of tests made in the wind tunnel of the Massachusetts Institute of Technology some years ago are that the upper surface is the more important in determining the prop-

erties of a thick-wing section, and that a small change in the upper camber makes a great alteration in the character of the aerofoil. The maximum ordinate must be very close to 1/3 of the distance from the leading edge, and the height of the ordinate must not exceed 1/6 of the chord, or the streamline flow will not persist at large angles. The L/D is not affected by small changes in the lower surface, which should be designed to permit

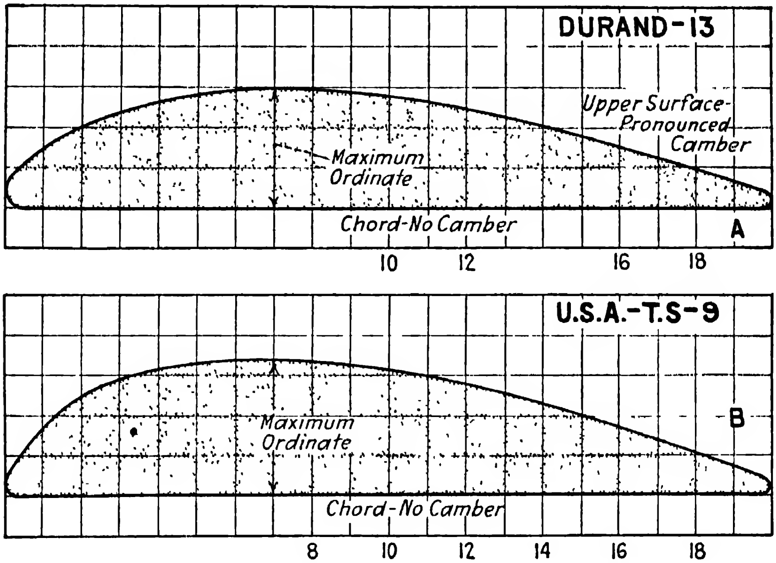


Fig. 40.—U. S. Army Thick Wing Sections Suited for Cantilever Monoplane Aerofoils. A—Durand No. 13, a Very Effective Form Having no Camber of Lower Surface. B—U. S. Army T. S. 9 Wing Section C and D Show Thick Wing Sections with Outwardly Curved Lower Camber, Such Wing Sections More Nearly Approximate Streamline Shape than Other Forms.

maximum depth of spars. Sections of great thickness may have heavily-rounded edges without in any way impairing their good qualities. If the reader will refer to the Ford-Stout three engine monoplane shown at Fig. 36, it will be evident that the leading edge is very heavily rounded and not sharp as is the case with thin-section biplane aerofoils. Another point to be noted in studying this airplane is that the aerofoil is a double cambered section. Two thick section aerofoils tried out by the U. S. Air Corps are shown at Fig. 40 C and D. Such aerofoils are not subject to the rapid center of pressure fluctuations with varying angles of incidence that the aerofoil having a lower camber as that in U. S. A. T.S. 8 shown at Fig. 39. The maximum L/D is not of such high value, as that of the T.S. 17 is but 12 while the T.S. 16 has a value of 12.2. The drag decreases for angles between —2° and 10° incidence with increased thickness until a double camber is reached. The L/D is a maximum when the lower surface is nearly flat as in Fig. 40 A and B and decreases if the camber is made either concave or convex, as in Fig. 39 B. A marked structural advantage of a double outward camber aerofoil is that it permits using deep section spars without too great sacrifice of aerodynamical properties.

Pressure Distribution on Aerofoils.—Consideration has previously been given to the various aerofoil sections and diagrams have been presented showing the supposed air flow about the cambered sections so that a definite lift could be obtained both from the positive pressure existing below the plane and the negative pressure existing above it. It is apparent that the greater part of the lift at normal angles of incidence is secured by the negative pressure and that this is always greater than the positive pressure below the plane regardless of angle of incidence. Pressure observations have been made by Eiffel and others with aerofoils of varying cross-sections and while numerous interesting deductions could be made by studying the entire series of tests, in a discussion of this character it is only necessary to study typical diagrams which show graphically the pressure distribution.

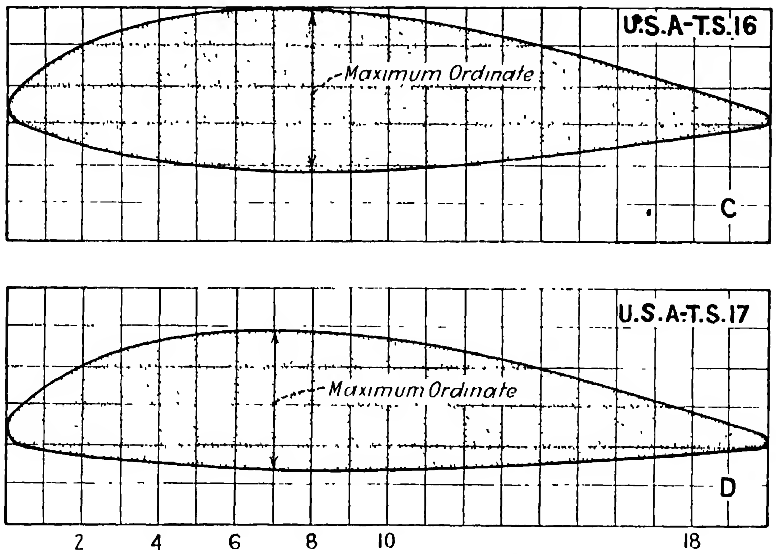


Fig. 40.—Continued—C and D—These Wing Sections More Nearly Approach Streamline Bodies.

Referring to Fig. 41 a deep cambered wing section is shown at A that has no perceptible angle of incidence. The pressure distribution is represented graphically by normals drawn from both upper and lower surfaces of the aerofoil and having the degree of pressure existing indicated by making the length of the lines proportional to the existing pressure. The positive lift is denoted by normals drawn from the lower surface down, while the negative pressure or suction lift is indicated by lines drawn normal to the upper cambered surface. It will be evident that at zero angle of incidence practically all of the lifting force present on the wing is produced by the negative pressure or suction lift above the cambered surface. There is a certain amount of negative pressure on the underside of the aerofoil at the entering edge which actually detracts from the efficiency by reducing the lift. It will be apparent that in the wing of a fast airplane,

the top surface should be so designed as to carry practically all of the load. The aerofoil tested had an aspect ratio of six and the tests were made at a wind speed of a mile per minute, or 60 miles per hour, which would correspond to a low flying speed even for an aeroplane having deeply cambered wing section and only moderate power.

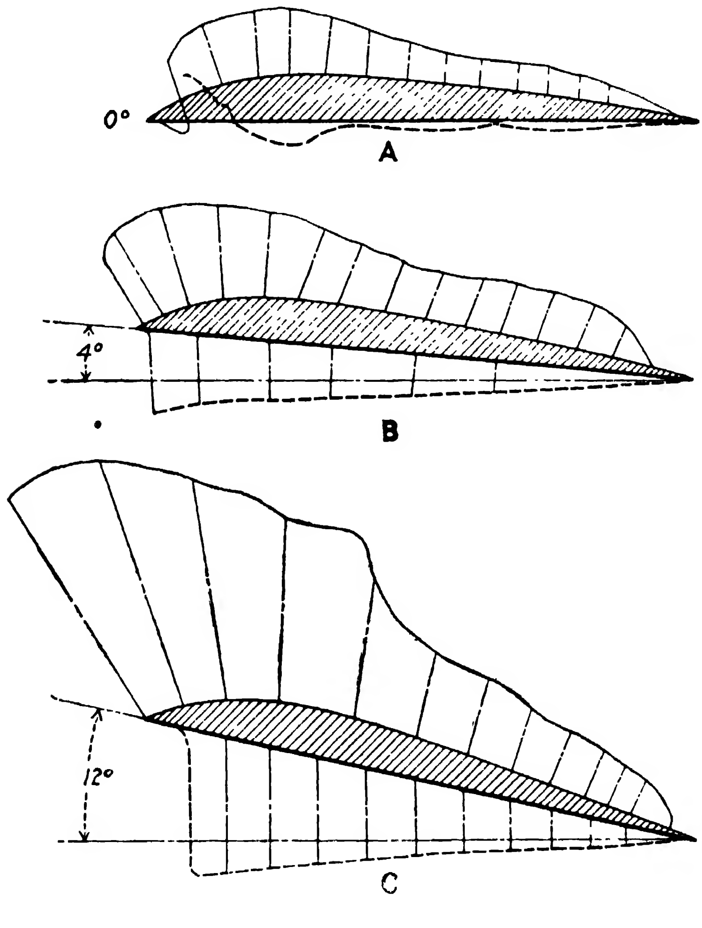


Fig. 41.—Graphic Diagrams Showing Pressure Distribution on Top and Lower Surfaces of a Cambered Aerofoil at Varying Degrees of Inclination.

U. S. A. Wing Sections.—The U. S. A. wing sections are a series of carefully designed aerofoils, the data for the contours of which was obtained by careful consideration, both from a structural and an aerodynamical viewpoint, of similar foreign and American sections. Good standard sections were refined and modified both from a theoretical and practical viewpoint and tested at the aerodynamical laboratory at the Massachusetts Institute of Technology. As all sections were tested at the same L/D ratio, and under standard conditions, a true comparison is at once pos-

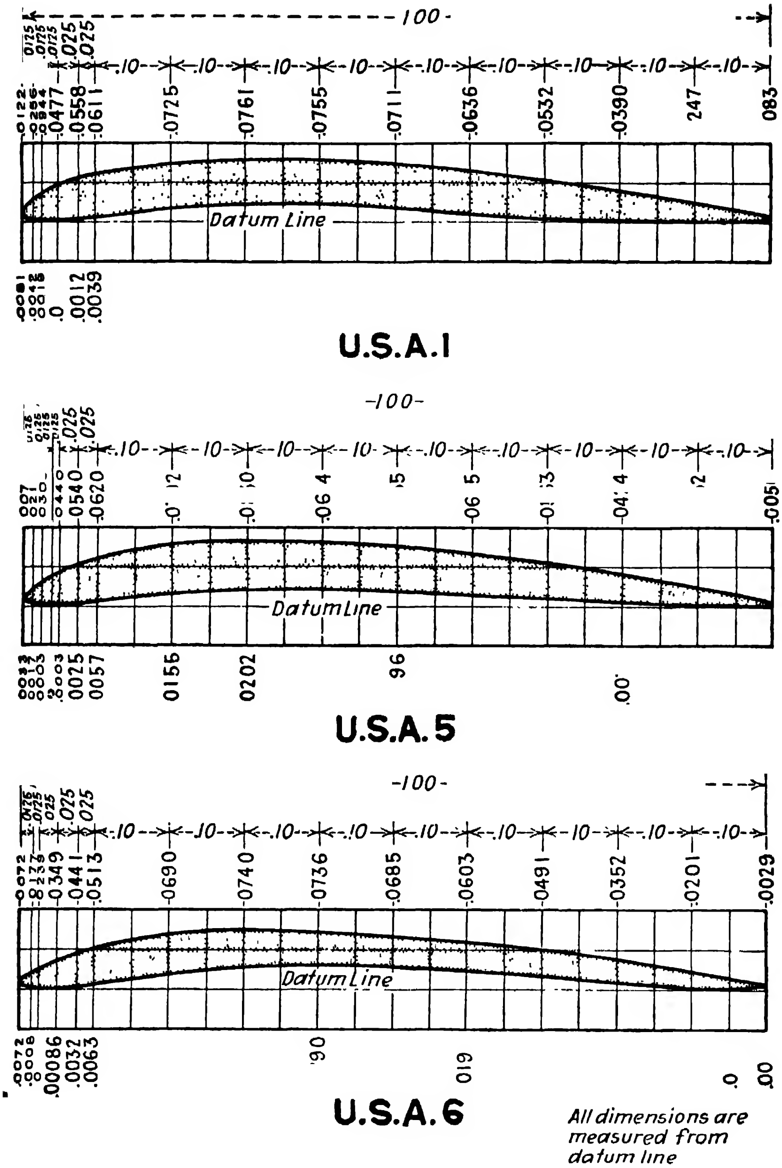


Fig. 41A.—U. S. A. Wing Sections Showing Proportions.

sible. Ordinates of sections, tables and curves for Ky, Kx, L/D and center pressure movement are appended. The most important of the sections are shown at Figs. 41A and 41B.

No useful purpose will be served by a lengthy discussion of the properties of the foregoing sections and any one interested in design can obtain full data regarding these wing sections from the technical section of the Air Corps. The center of pressure motion of all these wings is about identical and all the sections give ample depth for spars. In regard to

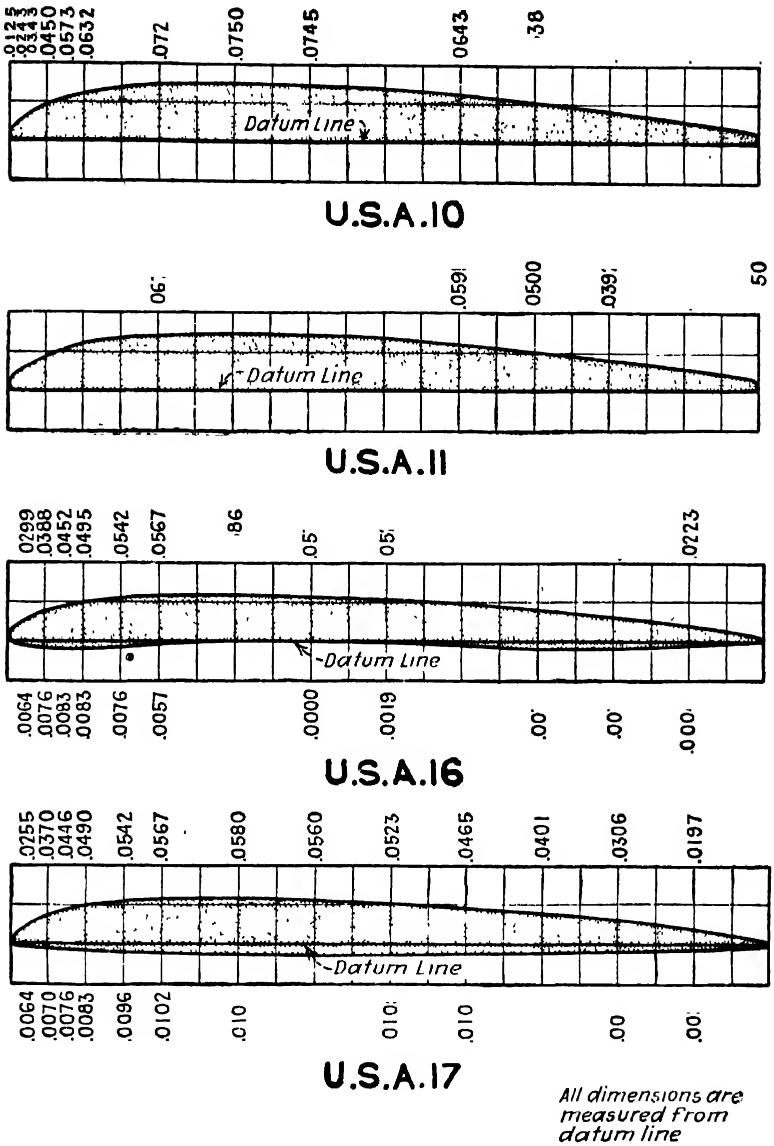


Fig. 41B.—Some Important Wing Sections Tested by U. S. A. Technical Division, Air Corps.

aerodynamic efficiency, it is still best, in spite of the many methods of comparison and plotting developed, to select two or three wings for a given airplane and draw up performance curves for each. The table appended may be of assistance in preliminary selection.

Landing speed depends upon the maximum Ky. Economical cruising speed depends upon the maximum L/D. Efficiency when climbing depends roughly upon L/D at 2/3 maximum Ky. Efficiency at medium speed twice minimum depends upon L/D at 1/4 maximum Ky, while at

high horizontal speed which may reach about 2¾ times the minimum, the efficiency of the wings depends up L/D at about 1/8 maximum Ky. The table enables one to select readily the two or three wings best fitted for the particular qualities most desired.

The well known British sections R. A. F. 3, 6, 14, 15, and 17 are included in the table for the purpose of comparison. The sections were all tested at Massachusetts Institute of Technology under the same conditions as the U. S. A. sections, hence the results may be compared directly.

Section U.S.A.	Max Ky	L/D when Ky—2/3 max.	L/D when Ky—1/4 max.	L/D when Ky—1/8 max.	Max L/D	Remarks
1	.00292	15.	11.3	5.6	16.7	
2	.00339	14.8	9.1	5.1	15.7	Good high altitude wing.
3	.00324	15.3	9.7	3.8	16.4	
4	.00364	13.9	8.7	4.0	15.9	Good for heavy machines.
5	.00328	14.6	11.4	4.5	16.2	
6	.00297	16.2	11.5	5.0	17.2	High climb.
10	.00287	14.4	12.2	4.3	16.4	
11	.00285	14.7	10.6	4.6	16.6	
14	.00286	15.1	11.2	6.0	16.4	
15	.00300	14.7	12.7	6.2	16.5	
16	.00252	15.1	15.2	6.5	18.8	Good for light machines at high altitudes.
17	.00275	14.5	13.2	7.4	16.0	Light speed scout wing.
RAF 3	.00348	14.7	7.8	3.0	15.6	
RAF 6	.00303	13.8	10.1	4.8	16.8	
RAF 14	.00326	13.6	11.1	3.0	15.4	
RAF 15	.00282	14.0	13.2	7.2	15.7	Inferior to U. S. A. 14-15-16.
RAF 17	.00280	13.6	10.6	5.1	14.2	

Inclination for Maximum Efficiency.— The maximum efficiency of the aerofoil was obtained with the wing at the position shown at Fig. 41 B in which the angle of incidence is 4 degrees as, while the lift is not as great as it is at a higher angle of incidence, it is at this position that the greatest lift is obtained with the least resistance. It will be observed that there is more uniform distribution of pressure upon both upper and lower surfaces, and while the value of the negative pressure is of considerably greater amount than that of the positive lift, both of these attain their greatest value but a short distance from the leading edge. At 12 degrees inclination, shown at Fig. 41 C which can be considered the position of maximum lift, the great increase in the negative pressure effect near the leading edge at this angle of incidence is easily noticed; also the progressive falling off toward the trailing edge.

Position of Center of Pressure.—From these graphic diagrams it will be evident that it is because of the greater magnitude of both positive and negative pressure effects near the leading edge that the center of pressure is nearer to the leading edge than to the center of the aerofoil section at ordinary angles of flight. While the position of the center of pressure varies, it may be stated to average about one-third of the length of the chord from the leading edge. With a certain aerofoil section the pressure upon the upper surface near the leading edge at an angle of inclination of 10 degrees and with a wind speed of a mile per minute is about 40 pounds per square foot, while near the trailing edge it is about 3 pounds per square foot only, which makes the average lifting force for the whole surface about 10 pounds per square foot.

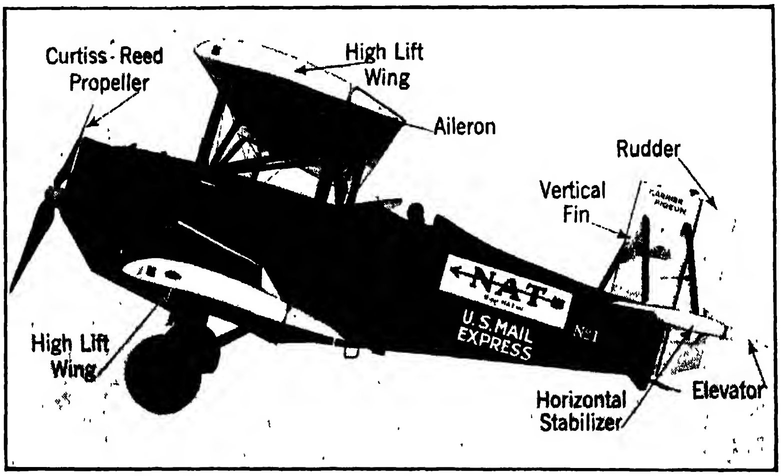


Fig. 42.—Curtiss Carrier Pigeon Plane for Mail and Express has High Lift Aerofoils in Biplane Relation.

What Is Meant by Critical Angle or "Burble" Point.—If an aerofoil is tilted from 0 incidence, the values of the suction lift or negative pressure on the top camber continually increase until a certain angle is reached which invariably lies betwen 14 degrees and 20 degrees, where a pronounced change in the values of the pressures occurs and where a further increase results in a practically uniform and reduced lift. This is called "the critical angle" because, as has been previously shown, the value of the lift coefficient becomes suddenly reduced, while the drift coefficient, which is a measure of resistance, increases greatly. The sudden change in the pressure distribution is sometimes called "the burblé point" and is evidently due to a sudden alteration of the air flow over the camber of the top surface of the aerofoil, and air flow in which there are so many eddy currents that there is a dead air region which offers resistance without producing any useful lifting effort.

Greatest Lift Produced by Upper Surface.—It will require but brief study of the graphic pressure diagram given at Fig. 41 to ascertain that of the total lifting force on a cambered surface aerofoil that the greatest lifting

effect is due to the negative pressure or suction lift on the upper surface. The amount of this lift will vary with the section of the aerofoil, and it may be stated to range from 75 per cent in the case of a flat plane to as high as 92 per cent in the case of a cambered plane at zero angle of incidence. In the case of aerofoils having a fairly flat lower surface, the upper surface at 0 degrees incidence practically supports the load. At 4 degrees the lower

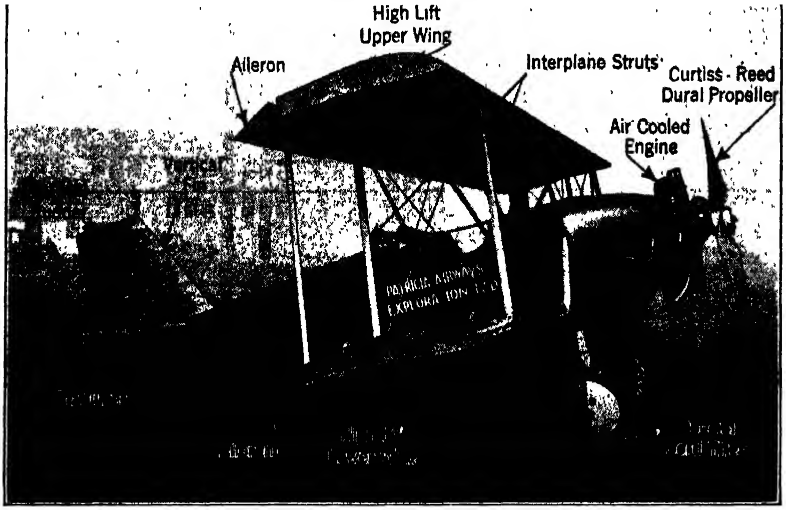


Fig. 43.—Curtiss Lark Three Place Passenger Plane with High Lift Moderately Thick Section Aerofoils. Note Radial Engine and Metal Propeller.

surface contributes but 18 per cent of the lifting effect. Aerofoils designed for fast flying are of such form that the upper surface contributes from 95 to 100 per cent of the total lift while in cambered sections designed for slower-speed machines the upper surface is responsible for from 65 to 85 per cent of the lifting influence. The following table shows the percentage of the total load carried by both surfaces in testing an aerofoil having a fairly high total lift.

TABLE VI

Percentage of Total Load Carried

Angle of Incidence	Lower Surface	Upper Surface
0 degrees	8	92
4	18	82
6	26	74
8	28	72
10	31	69

The figures given are useful as a guide but will vary with the type of aerofoil and also with its method of application, or if it is to be used as a component of a biplane structure or as a monoplane. A typical wing

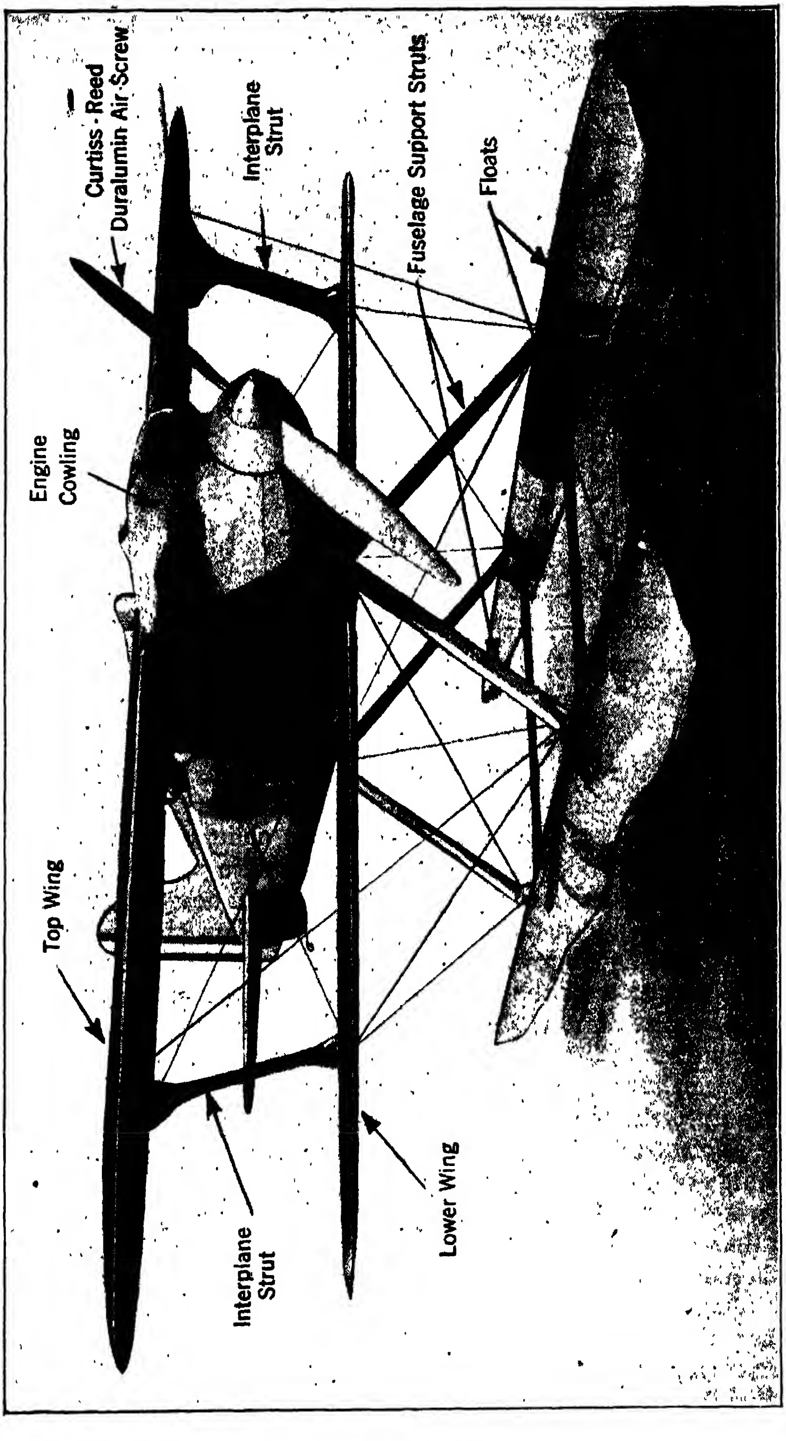


Fig. 44.—Curtiss Racing Twin Float Seaplane Showing High Speed Double Cambered Thin Section Aerofoils in Biplane Relation.

section used in a biplane structure intended for mail and express service that has shown good performance is that shown at Fig. 42 which depicts the Curtiss "Carrier Pigeon" and at Fig. 43 which shows a Curtiss "Lark" having accommodations for two passengers in the forward cockpit. Comparing these with the wings shown at Fig. 44, which shows the Curtiss Navy A26 racer is interesting in determining wide range of design.

Wing Having Varying Camber or Section.—Pressure distribution tests in the wind tunnel and static strength tests have recently been conducted at the Daniel Guggenheim School of Aeronautics of New York University for the wing used in the Edo Aircraft Corp flying boat, to the designs of B. V. Korvin-Kroukovsky, the chief engineer of this company by Prof. Alexander Klemin, were recently reported in "Aviation."

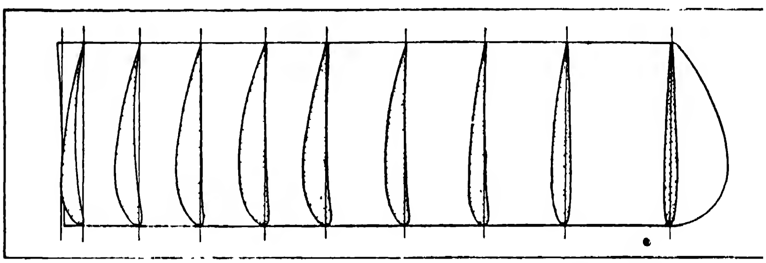


Fig. 45.—How Section of Edo Flying Boat Wing Varies to Meet Different Conditions of Loading along the Wing Span and to Secure Good Aerodynamical Properties.

The design of the wing panel provides a most interesting illustration of what skillful design can achieve in so varying the elements of a wing along its span as to produce desirable aerodynamic characteristics, and at the same time so as to provide spar depths corresponding to the loads imposed at different points of the wing span. The structural design of the wing also provides a novel and ingenious attack on the problem of eliminating twisting effects in a monoplane without resorting to multiple spar construction. The general character of the wing, for which the Aeromarine No. 2-A was used as the base section, is shown in Fig. 45. The wing has a high upper and lower camber at the root, with comparatively little spar depth. From the root outward, the upper camber increases slightly and the lower camber diminishes until there is a pronounced Phillips entry and spar depth is increased. Thereafter, the upper camber diminishes and the wing passes into a thin double-cambered section at the wing tips.

The wing meets the stress requirements of the design admirably. At the root there is a high camber, but comparatively little spar depth, which is as it should be, since the bending moments are zero at the hinge. Where both the maximum bending stresses and the direct compression of the left truss occur, the wing has its maximum spar depth. Toward the tip where the stresses are low, the spar depth reaches approximately a minimum value. But it is, perhaps, more remarkable that by utilizing the now generally accepted theory that the lift of a wing element depends not on the thickness but on the camber of the median line, the designer has combined

with excellent structural characteristics, a pressure distribution along the span which is highly desirable aerodynamically.

By the theory of induced drag for airfoils, it is advantageous to have an elliptical pressure distribution along the span of the wing. The induced drag due to the tip vortices is thereby reduced to a minimum for a given value of the lift coefficient. Reducing the induced drag is particularly important at high lift coefficient corresponding to climb, when the induced drag becomes the preponderating part of the total resistance of the wing. That elliptical lift distribution is advantageous has been demonstrated not only theoretically, but also in the wind tunnel. In the Gottingen experiments it was sought to obtain an elliptical lift distribution by progressive decrease in the angle of incidence or "wash-out" toward the tip. In the Edo wing, elliptical lift distribution has been obtained at both high incidence and low incidence without change in the angle of incidence.

Planes for Racing.—Professor Alexander Klemin, writing in the Scientific American discusses airplane speed possibilities in a very interesting manner. He says:

"Speed in airplane racing is more dependent on basic engineering skill and calculation than even with motor boats or racing cars. In basic principle the airplane has changed very little from the first Wright biplanes. A better wing, but still an inclined plane, provides sustention or lift; the same type of internal combustion motor, acting through the same type of propeller, overcomes the drag or air resistance; the same structural elements are present; practically the same system of air control. But what tremendous difference in the results attained! The secret of the difference lies in the tremendous refinement of each separate element. The Wright brothers were lucky to obtain 40 horsepower from their motor, which weighed nearly 200 pounds. In the race the Curtiss D-12 engine, undoubtedly the most wonderful racing motor in the world, developed fully 500 horsepower, yet it weighed well under 700 pounds, and its area, projected on a plane at right angles to the line of flight, is but a few square feet.

In the modern racer or fighting plane there is a tremendous concentration of power. The Curtiss racer weighed only 2097 pounds—not much more than four pounds per horsepower—and with this tremendous power the supporting surface is reduced to the minimum—148 square feet. Less area and but a few hundred pounds more weight than the Wrights flew with, when their motor developed but 40 horsepower and 40 miles an hour was a high speed. The wings of the racer are thin of camber; they provide comparatively little lift at a given speed, but their profile is really beautiful. In addition to the camber on the upper, there is a slight camber on the lower surface, giving the eye a definite impression of "streamline," of offering the very least resistance to motion of any sustaining surface ever designed. And the aerodynamical laboratory shows indeed that their efficiency as measured by the ratio of lift to resistance is over 20 to 1. In the early days of aviation 11 to 1 was considered good. Gone is the forest of struts and wires of biplane structures of early days. The wing bracing is now reduced to a minimum—a small I-shaped strut and three streamline wires on either side and direct attachment to the fuselage in the center. The body of the airplane is beautiful in its streamline form, no

part of the engine projects—it is all carefully cowled in—even the exhaust stacks are housed in a wing-like covering, and the pilot's cockpit is such that the air flows past it with a minimum disturbance. The chassis must still have rubber cord to absorb the shock of landing, but the entire system of shock absorption is housed within the wheels themselves, removing all harmful air resistance. The propeller is no longer a thick wooden blade, but a thin duralumin forging (as shown at Fig. 44) thinner and more efficient than is possible with the most carefully designed propeller in oak or mahogany. There is no clumsy automobile type of radiator in evidence. The engine works continuously at full power and must be cooled, but the cooling water circulates through the wings themselves and is therefore freed of its heat without imposing any resistance to motion. By the use of duralumin, strong as mild steel and one-third the weight, the weight of the entire structure is reduced to a minimum, explaining largely the extraordinarily low weight per horsepower it is possible to obtain in the modern racer."

Future Speed Possibilities.—The participation of the Army and Navy Air services in the Pulitzer races involves great expenditure. But it is fully justified. The general progress in performance, aerodynamics and construction evolved under the stress of racing conditions is immediately carried over into the construction of practical fighting ships. Ultimately it will be carried over into the field of commercial aviation in such degree of modification as experience will dictate. If 300 miles an hour were commercially possible, New York to San Francisco would mean less than 10 hours flying, a possibility which would certainly have value. The question arises whether the practical limit of airplane speed has now been reached. From the point of view of the engineer it undoubtedly has not. It is true that the utmost refinement has already been attained in structure, in the use of light materials, in aerodynamic streamlining, in improving wing efficiency and cutting down wing area, and in the power plant. We could fly faster with smaller wings, but then the landing speed would become prohibitively high. But there are still avenues of progress.

Suppose a wing could be practically used in which the camber or thickness could be varied at will. Camber is almost synonymous with lifting power. In making a get-away or on landing, the pilot would use a heavy camber to keep the speed down. Once in the air the camber would be reduced to a minimum so as to secure the maximum speed possible. It is difficult enough to build an airplane wing structure which shall be safe and adequately rigid without any moving contrivances, but still there seems no inherent reason why a practical method of camber control should not be developed sooner or later. Variable area has the same basic advantages as variable camber and may be another method of attacking the same problem. Yet a third method of varying at will the lifting capacity of the wing is in the famous Handley-Page slotted wing, whereby the opening of a carefully shaped slot in the leading edge of the wing, in combination with the pulling down of the trailing edge, produces extraordinary results, increasing the lift in some cases by 80 per cent.

It does not seem possible to diminish the resistance of the fuselage very greatly, but it is quite feasible to think of the landing gear being

withdrawn in flight into the fuselage, with a corresponding decrease in head resistance and increase in speed, provided always that a simple and entirely dependable mechanical contrivance can be found. In its present form the aviation engine is not susceptible of indefinite improvement in lightness or size for a given power, but experiments are being carried out both in Europe and the United States on what might be called crankless engines, in which the elimination of reciprocating motion has resulted in all the advantages of a gas turbine, namely, extreme compactness and light weight, without its inherent difficulties. Another line of approach in the securing of tremendously high speeds lies in flying at altitude. The supercharger can be made to maintain the full power of the engine at altitudes of 30,000 feet. Granted this fact, the speed of an airplane can be increased quite appreciably by flight at altitude, where the air offers less sustention but also less resistance.

New Aerodynamic Theory.—A practical, yet simple, explanation of the modern conception of aerodynamic drag is of great importance and until this is fully understood, it will not be possible adequately to adapt modern theory in this connection to airplane design problems, such as the estimation of power consumption and power required under certain conditions in airplanes.

A very considerable amount of mathematical and experimental work has, in the past, been carried out on the aerodynamic theory of airfoils and other allied subjects and much has been published as a result of these researches, although all of the work, almost without exception, has been of a character far over the heads of many aeronautical engineers and airplane designers for the simple reason that the mathematics involved have

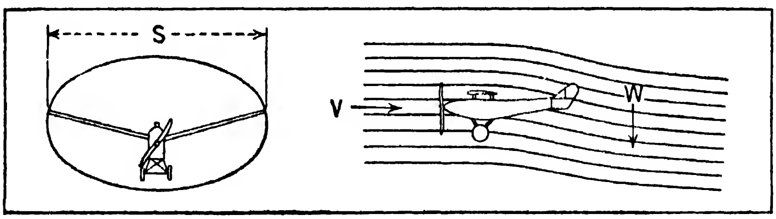


Fig. 46.—Illustrating Induced Drag of Airplane.

been of a highly specialized and complicated nature. The results of all this work are, however, of very vital importance to the practical engineer for upon the very latest conceptions of aerodynamic theory must rest, to a large extent, the degree of aerodynamic efficiency possible in the most modern application of design.

Theory, in the main, has resolved itself into a thorough investigation of the drag of airfoils, etc., and the resolution of much of the theoretical work which has been done into a form in which its application to airplane design is practical has been a problem upon which the Air Service Engineering Division at McCook Field has given considerable attention, culminating in the recent publication of an "Air Service Information Circular" Vol. VI, No. 560, entitled, "Notes on Airplane Performance from the Standpoint of the Modern Conception of Drag."

Parasitic and Induced Drag.—The drag of an airplane is made up of two different parts:

a. The parasite drag results from friction of the air on the parts of the airplane, including the wings, tail, fuselage, landing gear, etc., and from the eddies set up by these parts when in motion. It is assumed for the sake of simplicity that it follows the familiar law.

$$\text{Parasitic drag} = 0.00327\ A_e\ V^2$$

where A is the area of a flat plate normal to the airflow having the same drag as the parts considered, and V is the relative speed.

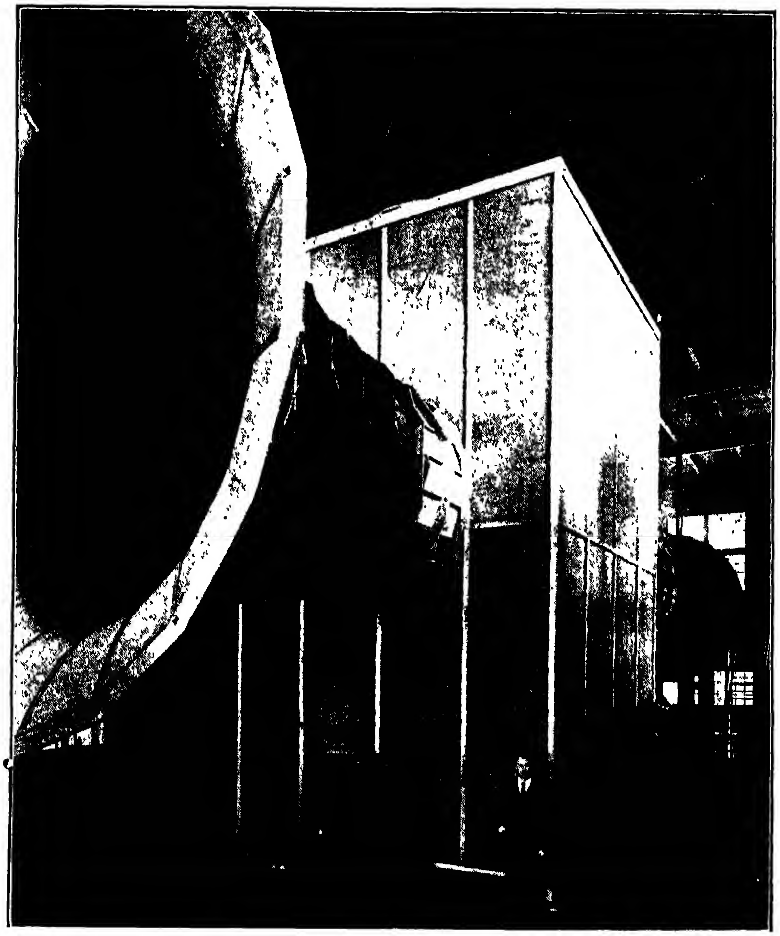


Fig. 47.—Exterior View of Curtiss Wind Tunnel.

b. The induced drag, as its name implies, is induced by the airplanes' own downwash. This drag follows a different law of variation from the first, namely:

$$\text{Parasitic drag} = 125 \cdot \frac{L^2}{S^2\ V^2}$$

where L is the lift and S the span of a monoplane wing. In both cases the units are pounds, feet, and miles per hour.

The notion of parasite drag, equivalent flat plate and their applications are quite familiar, but heretofore the equivalent flat plate has never been made to include the friction drag of the airfoils. The modern viewpoint requires that this friction drag be considered as a separate part of the wing drag, since it varies according to a different law than the rest of the wing drag. For each good airfoil the drag has a nearly constant value within the speed range, increasing gradually as the burble points are reached. An airfoil must be considered as having two burble points, one at the angle of attack of maximum positive lift, the other at the angle of maximum negative lift. Ordinarily the latter occurs when this negative lift has a considerable magnitude, but for some deeply cambered sections it may occur near the value of zero lift, or at some low values of positive lift.

Thus when the deductions and estimates are based on the assumption that the airfoils' friction drag is nearly constant, care must be taken that the airfoil is really operating well between the burble points.

The value of airfoil friction drag is determined by subtracting the induced drag from the total drag.

The ratio of maximum lift to friction drag is a good measure of the excellence of an airfoil. This quantity does not assume any value for induced drag which is usually varied at will through changes in aspect ratio.

Tables 7 and 8 show the parasite drag of typical airfoils and airplanes.

TABLE VII

Parasite coefficients of various airfoils.
(From Massachusetts Institute of Technology test; 40 miles per hour 36 by 6 airfoils)

Airfoil	Minimum friction drag	Ky Maximum - Minimum; friction drag	Ky maximum
U. S. A. 45	0.0000276	0.00334	120.0
Clark Y	.0000269	.00318	118.2
U. S. A. 35	.0000334	.00383	114.5
R. A. F. 15	.000025	.0026	104.0
Gott. 430	.000033	.00338	102.5
U. S. A. 27	.0000345	.00346	99.8
Gott. 436	.0000313	.00310	98.0
Gott. 387	.000041	.00366	89.3

Value of Induced Drag.—The value of induced drag is determined in the following manner:

As an airplane flies it disturbs a cylinder of air, Fig. 46, and imparts a certain downward motion to it. The mass of air affected per unit of time is

$$m = K_p S^2 V \tag{1}$$

where K is a coefficient determined experimentally or theoretically.

P is the air density = 0.00237

S is the span in feet.

V is the speed of the airplane in feet per seconds.

A downward velocity w is imparted to this air, and the airplane must climb at that rate in order to maintain its path; to do this, work is expended at the rate L w, L being the lift. This work is performed by a thrust which is equal to the induced drag D_{ind}

so that
$$Lw = VD_{ind}$$

and
$$D_{ind} = \frac{Lw}{V} \tag{2}$$

Now the lift produced by imparting the downward motion to the air is

$$L = mw = K_p S^2 V w$$

$$w = \frac{L}{K_p V S^2} \tag{3}$$

substituting (3) in (2)

$$D_i = \frac{L^2}{K_p V^2 S^2} \tag{4}$$

K has been given the following values

1.57 for monoplane
1.89 " biplane with gap-span ratio 1:10
2.84 " biplane with gap-span ratio 1:6

This means that biplanes, for the same actual span and area make use of greater quantities of air than monoplanes do and more as the gap is increased. This leads to the notion of equivalent monoplane span which is necessary for comparing biplanes of varying gap to span ratios. It is possible to use, as a constant value for K, the monoplane value 1.57, the numerical constants in formula (4) are usually combined so V can be expressed in miles per hour and the usual form of the formula is

$$D_{ind} = \frac{L^2}{1.57 \times 0.00237 \times 1.467^2 V^2 S^2} \tag{5}$$
$$= 125 \frac{L^2}{S^2 V^2}$$

The horsepower required for overcoming induced drag is:

$$H\,P_{ind} = \frac{125}{375} \frac{L^2 V}{S^2 V^2} = \left(\frac{L}{S}\right) \frac{21}{3V} \tag{6}$$

The factor $\frac{L}{S}$ is called span loading. It is the only factor depending

on the dimensions of the airplane which affects induced drag or induced power. S is always the span of the equivalent monoplane. If two airplanes have the same equivalent monoplane span loading, their induced drag will be the same at each speed regardless of their size. Induced drag is that portion of the drag that can never be eliminated by streamlining or changing wing sections, it is the direct consequence of obtaining lift with an airfoil of finite span. In order to have the maximum equivalent monoplane span with a given span and gap, a multiplane must have the best possible lift to drag ratio, which condition requires adjustment of the lift distribution between the airfoils. This can be accomplished by a certain amount of decalage or difference in upper and lower wing sections and this varies with the ratio of spans, of chords and amount and nature of stagger. There is no simple method of solving the best value for these variables, mathematically. Wind tunnel tests with models will give values experimentally. Stagger varies the induced drag or lift of the upper and lower wings but does not affect the total amounts of these quantities for the cellule.

TABLE VIII

Parasite areas of various airplanes.

Airplane	Weight	(Ae) Total	(Ae) Wing	(Ae) Structure
XBI-A	3,590	13.5	3.1	10.4
JL-6	3,605	13.5	4.5	9.0
VE-9	2,269	8.4	2.1	6.3
CO-5	4,193	12.8	4.7	8.1
CO-4	4,493	14.5	4.5	10.0
MB-2	10,363	58.8	10.6	48.2
PW-8	2,784	8.1	2.0	6.1
Messenger	862	5.5	1.8	3.7
DeH-4	4,297	17.55	3.35	14.20
SE-5A	2,060	9.33	1.88	7.45

Various charts and other formulae are given in the paper from which these excerpts have been taken and as the publication is a public document it can be obtained by any interested designer or student. Only enough has been presented so the reader of this treatise will have a definite idea of what "induced drag" and "equivalent monoplane span" are and how they may be used. Unfortunately, the general determination of equivalent monoplane span of multiplanes is a difficult problem and no precise mathematical solution is yet available, because authorities are not yet agreed on the variables affecting the problem or the values they have. Much depends on experimental determinations. This new point of view, which some designers say greatly simplifies computations requires that such conceptions as aspect ratio, gap-chord ratio, L/D, D/L, be used less frequently; while other new quantities such as equivalent monoplane span, span loading, gap to span ratio, wing friction drag, etc., must be used in their place. The new theory does not point the way to any changes in

physical aspects of airplanes nor does it bring greater accuracy to the prediction of performance. It rests upon the designer as to what method of computation he will use and upon what basis his figures will be premised. No matter how the figures are arrived at, a scale model will be constructed and tried in the wind tunnel to verify theoretical assumptions.

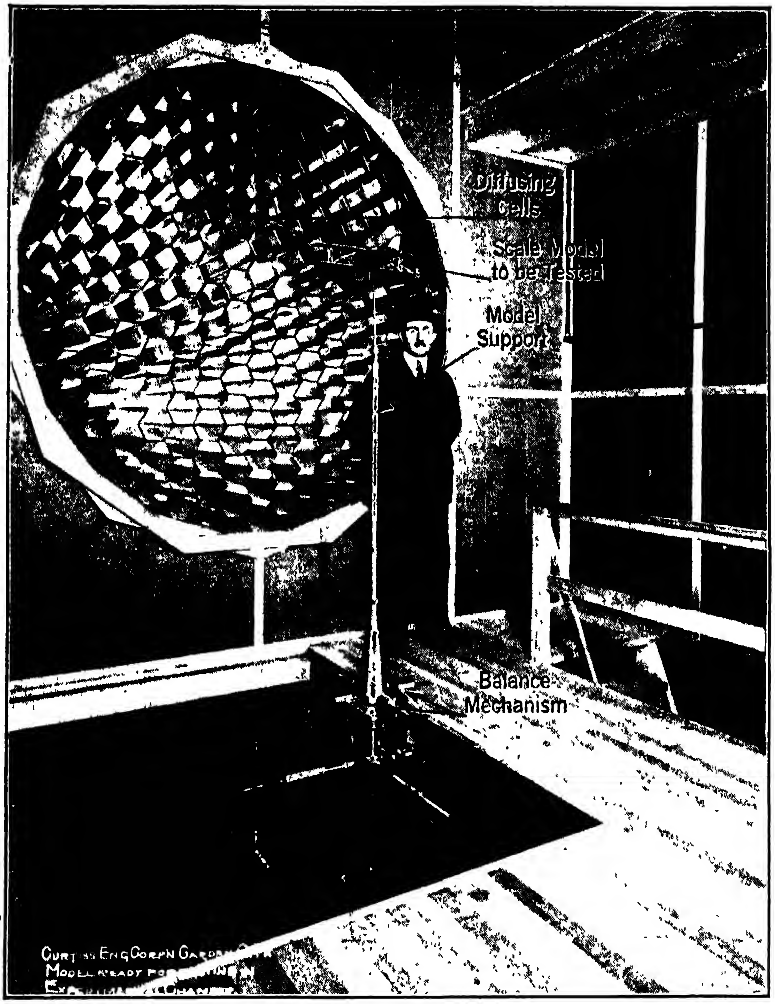


Fig. 48.—Showing Diffusing Honeycomb to Straighten out Air Stream and Model Airplane Being Tested at End of Spindle. Note Balance Weight on Base of Spindle Carrier.

What a Wind Tunnel Is.— While everyone who has had experience in airplane design knows the great value of a wind tunnel and appreciates how much data can be obtained experimentally that has great practical value, the novice or student just becoming familiar with some of the rudiments of aeronautical engineering, may not have more than a general idea of what a wind tunnel is and how it works.

One of the most important items of Curtiss engineering equipment is the 7 foot wind tunnel which is housed in a special building at the Garden City plant. This wind tunnel is of the Eiffel type and consists of a bell-mouthed tube 70 feet long and 7 feet at its smallest diameter, through which air is drawn at high speed by a 12 foot propeller driven by a 400 horse-power motor. An exterior view is shown at Fig. 47. Accurate scale models of aeroplanes, wings, etc., are mounted on a spindle which projects into the air stream, and is connected to an extremely sensitive balance, which measures the air pressure on the model to one ten-thousandth of a pound. The method of mounting a model on the spindle is shown at Fig. 48 and the aerodynamic balance is shown at Fig. 49. By this means Curtiss engineers are able to predict, with absolute accuracy, the speed, stability and flying qualities of each new aeroplane designed, before building it. In addition, constant research is being carried on in the tunnel by a highly trained technical staff, to determine the aerodynamic properties of new types of wings, control surfaces, etc. A well equipped model shop, manned by experienced craftsmen, provides models, accurate to within one-thousandth of an inch, for testing in the tunnel. The Curtiss tunnel, in point of size and excellence of scientific equipment, is one of the finest in the world. It is the only wind tunnel in the United States which is owned and operated by an airplane constructor—one of the outstanding reasons for the consistent excellence of Curtiss designs and their aero-dynamical performance.

Aerodynamic Terms

Axes, Angles, Forces, Etc.

aerodynamic volume (airship)—The volume of the form which must be driven through the air. Same as "air-volume."

aileron angle—The angular displacement of an aileron from its neutral position. It is positive when the trailing edge of the aileron is below the neutral position.

angle of attack—The acute angle between the chord of an airfoil and its direction of motion relative to the air. (This definition may be extended to other bodies than airfoils.) Its symbol is **a.** Sometimes called angle of incidence. (Fig. 22.)

angle of pitch—The acute angle between two planes defined as follows: One plane includes the lateral axis of the aircraft and the direction of the relative wind; the other plane includes the lateral axis and longitudinal axis. (In normal flight the angle of pitch is, then, the angle between the longitudinal axis and the direction of the relative wind.) This angle is denoted by Θ and is positive when the nose of the aircraft has risen.

angle of roll, or angle of bank—The acute angle through which an aircraft must be rotated about its longitudinal axis in order to bring its lateral axis into a horizontal plane. This angle is denoted by Φ and is positive when the left wing is higher than the right.

angle of yaw—The acute angle between the direction of the relative wind and the plane of symmetry of an aircraft. This angle is denoted by Ψ and is positive when the aircraft has turned to the right.

attitude—The position of an aircraft as determined by the inclination of its axes to some frame of reference. If not otherwise specified, this frame of reference is fixed to the earth.

Fig. 49.—Lower Part of Aerodynamic Balance with which Forces and Their Reactions are Measured. Despite its Large Size and Weight, the Balance will Show Extremely Small Loads.

axes of an aircraft—Three fixed lines of reference, usually centroidal and mutually perpendicular. The longitudinal axis in the plane of symmetry, usually parallel to the axis of the propeller is called the longitudinal axis; the axis perpendicular to this in the plane of symmetry is called the normal axis; and the third axis perpendicular to the other

two is called the lateral axis. In mathematical discussions, the first of these axes, drawn from front to rear, is called the X axis; the second, drawn upward, the Z axis; and the third, running from right to left, the Y axis.

basic load—The load on an aircraft when it is at rest or in a condition of unaccelerated rectilinear flight (for purposes of stress analysis).

critical angle—An angle of attack at which the flow about an airfoil changes abruptly with corresponding abrupt changes in the lift and drag.

cross-wind force—The component perpendicular to the lift and to the drag of the total air force on an aircraft or any part thereof. Its symbol is C and its absolute coefficient is Cc is defined by

$$Cc = \frac{C}{qS}$$

where q is the impact pressure $(= \frac{1}{2} p\ V^2)$ and S is the effective area of the surface upon which the air force acts.

downwash angle—The angle through which an air stream is deflected by any lifting surface of an airplane. It is measured in a plane parellel to the plane of symmetry, and is denoted by the symbol e.

drag—The component parallel to the relative wind of the total air force on an aircraft or airfoil. Its symbol is D.

The "absolute drag coefficient" is C_D as defined by the equation

$$C_D = \frac{D}{qS}$$

in which D is the drag, q is the impact pressure $(= \frac{1}{2} p\ V^2)$ and S is the effective area of the surface upon which the air force acts.

In the case of an airplane, that part of the drag due to the wings is called "wing drag"; that due to the rest of the airplane is called "structural drag" or "parasite resistance." (Fig. 22.)

induced—That portion of the wing drag induced by, or resulting from, the generation of lift. (Fig. 46.)

profile—That portion of the wing drag which is due to friction and turbulence in the fluid and which would be absent in a nonviscous fluid.

dynamic lift—The lift impressed on an aerostat by aerodynamic forces.

dynamic load—Any load due to accelerations of an aircraft, and therefore proportional to its mass.

dynamic (or impact) pressure—The product $\frac{1}{2} p\ V^2$, where p is the density of the air and V is the relative speed of the air. It is the quantity measured by most air-speed instruments. Its symbol is q.

dynamic trim—Trim (or trimming) due to dynamic conditions or their change.

elevator angle—The angular displacement of the elevator from its neutral position. It is positive when the trailing edge of the elevator is below the neutral position.

lift—That component of the total air force on an aircraft or airfoil which is perpendicular to the relative wind and in the plane of symmetry. It must be specified whether this applies to a complete aircraft or to parts thereof. In the case of an airship, this is often called "dynamic lift." Its symbol is L.

The "absolute lift coefficient" is C_L as defined by the equation

$$C_L = \frac{L}{qS}$$

in which L is the lift, q is the impact pressure $\left(\frac{1}{2} \rho V^2\right)$ and S is the effective area of the surface upon which the air force acts. (See Fig. 22.)

minimum gliding angle—The acute angle between the horizontal and the most nearly horizontal path along which an airplane can descend steadily in still air when the propeller is giving no thrust.

Reynolds Number—A name given the fraction, $\rho \frac{Vl}{u}$, in which

ρ is the density of the fluid;
V is the relative velocity of the fluid;
l is the linear dimension of the body;
u is the coefficient of viscosity of the fluid.

rudder angle—The acute angle between the rudder and the plane of symmetry of the aircraft. It is poistive when the trailing edge has moved to the left with reference to the normal position of the pilot.

rudder torque—The twisting moment exerted by the rudder on the fuselage. The product of the rudder area by the distance from its center of area to the axis of the fuselage may be used as a relative measure of rudder torque.

skin friction—The tangential component of the fluid force at a point on a surface.

static lift (aerostat)—The resultant upward force on an aerostat at rest obtained by multplying the actual volume of the air displaced by the density of the air and subtracting the weight of the contained gas. (The volume of the air displaced, multiplied by the difference of density of the air and the contained gas.)

static trim—Trim (or trimming) due to static conditions or their change.

zero-lift angle—The angle of attack of an airfoil when its lift is zero.

zero-lift line—A line through the trailing edge of an airfoil section parallel to the direction of the wind when the lift is zero.

Miscellaneous Terms

airfoil—Any surface designed to be projected through the air in order to produce a useful dynamic reaction. (Fig. 38.)

airfoil section (or profile)—A cross section of an airfoil made by a plane parallel to a specified reference plane. A line perpendicular to this plane is called the axis of the airfoil. (Fig. 45.)

aspect ratio—The ratio of span to mean chord of an airfoil; i. e., the ratio of the square of the maximum span to the total area of an airfoil.

camber—The rise in the curve of an airfoil section from its chord, usually expressed as the ratio of the departure of the curve from the chord to the length of the chord. "Upper camber" refers to the upper surface of an airfoil and "lower camber" to the lower surface; "mean camber" is the mean of these two.

center of pressure coefficient—The ratio of the distance of the center of pressure from the leading edge to the chord length. (Fig. 24.)

center of pressure of an airfoil section—The point in the chord of an airfoil section, prolonged if necessary, which is at the intersection of the chord and the line of action of the resultant air force. Its abbreviation is C. P. (Fig. 24.)

chord (of an airfoil section)—The line of a straight edge brought into contact with the lower surface of the section at two points; in the case of an airfoil having double convex camber, the straight line joining the leading and trailing edges. (These edges may be defined, for this purpose, as the two points in the section which are farthest apart.) the line joining the leading and trailing edges should be used also in those cases in which the lower surface is convex except for a short flat portion. The method used for determining the chord should always be explicitly stated for those sections with regard to which ambiguity seems likely to arise. (Fig. 40.)

chord length—The length of the projection of the airfoil section on its chord. Its symbol is c.

leading edge—The foremost edge of an airfoil or propeller blade. Also called "entering edge." (Fig. 28.)

span (airfoil)—The lateral dimension of an airfoil; i. e., its dimension perpendicular to its chord. Its symbol is b.

streamline—The path of a small portion of a fluid relative to a solid body with respect to which the fluid is moving. The term is commonly used only of such flows as are not eddying, but the distinction should be made clear by the context.

streamline flow—Steady flow past a solid body; i. e., a flow in which the direction at every point is independent of time.

streamline form—A solid body which produces approximately streamline flow.

trailing edge—The rearmost edge of an airfoil or propeller blade. (Fig. 28.)

wind tunnel—An elongated chamber, usually a tube divergent at the ends, through which a steady air stream may be drawn or forced. Models of airfoils, of aircraft, or of propellers may be placed in the middle portion of the tunnel, called the experiment chamber or working section, and supported by suitable balances placed outside the air stream, so that the forces, moments, etc., due to the moving air may be measured. (Figs. 47, 48, 49.)

Wing Parts

aileron—A hinged or pivoted movable auxiliary surface of an airplane, usually part of the trailing edge of a wing, the primary function of which is to impress a rolling moment on the airplane.

antidrag wire—A wire designed primarily to resist forces acting parallel to the chord of the wing of an airplane and in the same direction as the direction of flight. It is generally inclosed in the wing.

cabane—A framework for supporting the wings at the fuselage; also applied to the system of trussing used to support overhang in a wing.

drag strut—A fore-and-aft compression member of the internal bracing system of a wing.

drag wire—Any wire or cable designed primarily to resist drag forces.

internal—A drag wire concealed inside the wing.

external—A drag wire run from a wing to the fuselage or other part of the airplane.

king-post—The main compression member of a trussing system applied to support a single member subject to bending.

landing wire—A wire designed primarily to resist forces in the opposite direction to the normal direction of the lift and to oppose the lift wire and prevent distortion of the structure by an overtightening of those members. Sometimes called "anti-lift" wire.

lift wire—A wire or cable which transmits the lift on the outer portion of the wing of an airplane in toward the fuselage or nacelle. This wire usually runs from the top of an interplane strut to the bottom of the strut next nearer the fuselage. Sometimes called "flying wire."

main supporting surface—A set of wings, extending on the same general level from tip to tip of an airplane; e. g., a triplane has three main supporting surfaces. The main supporting surfaces include the ailerons, but no other surfaces intended primarily for control or stabilizing purposes.

panel—Where a wing surface comprises several units of construction, these units are designated as panels.

skid fin—A fore-and-aft vertical surface, usually placed above the upper wing, designed to provide vertical keel surface and so to increase lateral stability.

stagger wire—A wire connecting the upper and lower surfaces of an airplane and lying in a plane substantially parallel to the plane of symmetry. (Also called "incidence wire.")

wing—A general term applied to a whole or a portion of the main supporting surfaces of an airplane but in the latter case is usually qualified as right wing, left wing, upper wing, or lower wing, etc.

wing rib—A fore-and-aft member of the wing structure of an airplane, used to give the wing section its form and to transmit the load from the fabric to the spars. (Fig. 28.)

compression rib—A heavy rib designed to have the function of a wing rib and also to act as a strut opposing the pull of the wires in the internal drag truss. (Also called "drag strut.")

former or false rib—An incomplete rib, frequently consisting only of a strip of wood extending from the leading edge to the front spar, which is used to assist in maintaining the form of the wing where the curvature of the airfoil section is sharpest.

wing spar—The principal transverse structural member of the wing assembly of an airplane. (Fig. 28.)

wing truss—The framing by which the wing loads of an airplane are transmitted to the fuselage. It comprises struts, wires, cables, tie rods, and spars.

QUESTIONS FOR REVIEW

1. What is the meaning of, "lift and drift" ratio and what influence does it have in choosing an aerofoil?
2. Define "center of pressure" and tell where it is located on a rectangular aerofoil.
3. What are the properties of cambered aerofoils that make them valuable for airplane use?
4. Why should the leading edge of an airplane wing be curved down?
5. What effect does wing loading have on airplane wing design?
6. What is the difference between a "high lift" monoplane wing and the usual biplane wing.
7. Outline influence of varying top and bottom camber on lifting ability of aerofoil sections.
8. Is pressure distribution uniform on aerofoil surfaces?
9. What is critical angle or "burble point" and how is it influenced by aerofoil design?
10. Define the three axes of an aircraft and name them. What is "induced drag."

CHAPTER V

ARRANGEMENT, FABRICATION AND BRACING OF AIRPLANE WINGS

Monoplane or Biplane—Effect of Gap Variation—Effect of Stagger—Aerofoil Plan Forms—Rectangular Plane Least Efficient—Securing Uniform Pressure Distribution—Wood and Fabric Wing Construction—Spars and Ribs—Glue for Laminated Construction—Tests of Plywood Ribs—Weight and Thickness of Plywood—Wing Covering Fabric—Why "Dope" is Used on Wings—U. S. Navy "Doping" Practice—Light Proof Dope—Effect of Light on Dope—How Fabric is Fastened—Metal Wings—Navy Practice for Experimental Metal Ribs—Rohrbach Wing—Airplane Wing Bracing—Loads on Airplane Wing Wires—Airplane Wing Form—Planes with Longitudinal Dihedral—Influence of Lateral Dihedral—Biplane Wing Bracing—Side Bracing of Biplane Wings—Airplane Bracing Wires—Hard Wire Loops—Flexible Cable Ends—Galvanized Non-Flexible Ends—Non-Corroding Soldering Flux—Thimbles—Turnbuckles—U. S. Army Bracing Wire Practice—Cables—Streamline Wire—Round Swaged Wire—Soldering and Serving—Tests of Spliced Cables—Typical Wire Bracing Arrangements.

Monoplane or Biplane.—The latest developments in airplane construction have resulted in such a great increase of efficiency for the monoplane type that it is now used in applications that would formerly have been thought impractical. In the early days the monoplane was the type used for carrying light loads at high speeds while the biplane was the form favored for carrying heavy loads at relatively slower speed but at the present time we have monoplanes of extremely large span capable of carrying very heavy loads. Due to the use of metal aerofoil structures large monoplane-seaplane structures are projected that will have a span of 240 feet so it cannot be said that modern engineers recognize the structural limitations of even a decade back. The biplane is undoubtedly the form having the greatest structural strength if one is limited to wood and fabric construction as well as permitting one to obtain the greatest amount of carrying surface in the most compact form. For example, if we consider a biplane having 40 feet spread with a 6 foot chord we have planes having a surface of 240 square feet each or a total of 480 square feet for the two planes. If one desired to obtain this same area in a monoplane and did not wish to depart from an efficient aspect ratio it would be necessary to use a single plane having a 60 foot spread and an 8 foot chord. It will be apparent that the design of a wing structure of these dimensions made of wood and fabric would be somewhat of a problem and it would require a high grade of engineering to have a strong wing skeleton which would be properly braced without making the framework too heavy.

As the weight that can be sustained with a given amount of power depends largely upon the area of the useful supporting surface and the velocity of the plane through the air, it is evident that if one decreases the supporting surface that one lessens the carrying ability. Of course, if more power is provided and higher speeds obtained the wing loadings can

be increased from the average value of 5 or 6 pounds per square foot to twice that amount, but this can be secured only by the sacrifice in low landing speed. The reason why the monoplane was favored even in the early days was because plane forms and their proper relation had not been as carefully studied as they have been in recent years. It was found that the efficiency of a surface was reduced if other planes were carried near it. It was therefore necessary to correct monoplane values in making computations to allow for the biplane arrangement of aerofoils, as the writer has

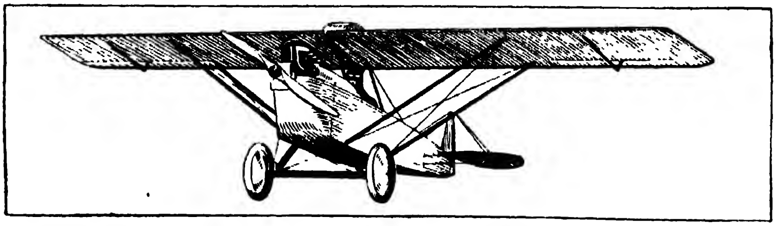


Fig. 50.—The Heath Parasol Monoplane, a Low Price Airplane that Flies with a Modified Four Cylinder Air-Cooled Motorcycle Engine.

previously pointed out in the preceding chapter. Where a large supporting area is necessary with a limited span, the biplane type is used but where practical considerations do not limit the span arbitrarily, then the monoplane, especially the all-metal internally braced aerofoil type is superior from an aerodynamical efficiency view point. The monoplane lends itself well to the small sport plane as shown at Fig. 50 which shows a Heath "Parasol" type. A larger monoplane, the Travelair cabin type is shown at Fig. 51. Both of these use externally braced wings and have more resistance than the monoplanes illustrated in other chapters that have internal bracing and no exposed struts or wires. A Travelair Biplane of excellent design is shown at Fig. 52.

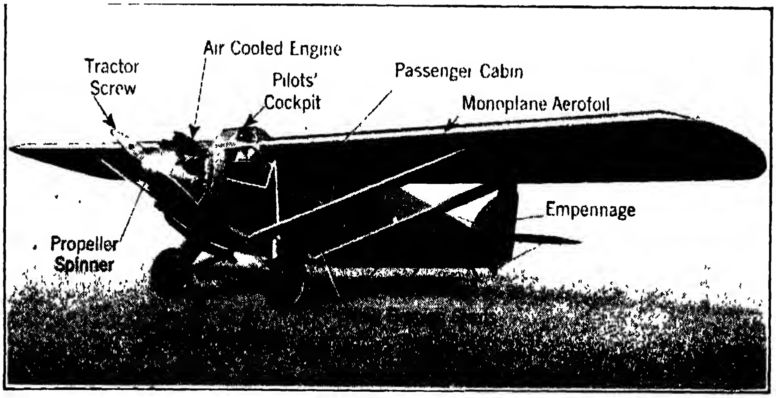


Fig. 51.—The Travel Air Cabin Monoplane, a Recent Type Adapted for Passenger Carrying and Other Commercial Work.

Effect of Gap Variation.—The results of wind tunnel tests upon exactly similar aerofoils arranged one above the other shows that there is a dis-

advantageous interference due to conflicting air currents between the two planes unless there is a gap between the planes of at least twice the chord. If the gap between the planes is less than this figure there is a reduction in the lift effect of the two planes. The condition can be easily understood if one refers to the diagram at Fig. 53 A, which shows two planes separated by a distance equal to only half of the chord. It will be evident that there is a large area of disturbed air between the two planes. This results in a reduction of the positive lift on the upper plane and of the negative lift on the lower one. We then have two surfaces working at greatly reduced efficiency and we are depending upon the efficient upper surface of the top aerofoil and the efficient lower surface of the lower aerofoil.

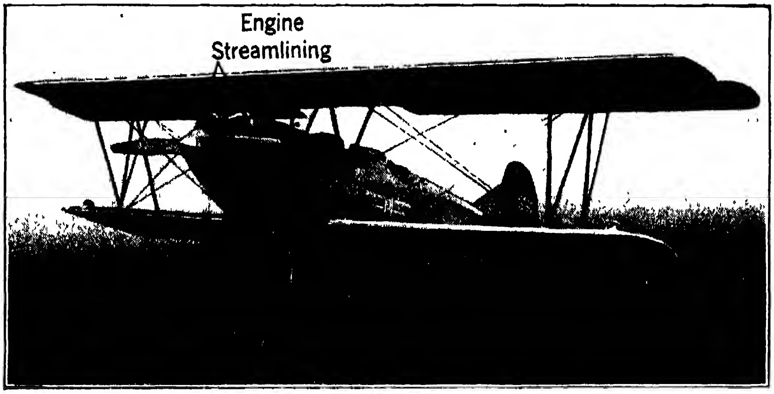


Fig. 52.—The Travel Air Biplane, Open Cockpit Type, Powered with Curtiss OX 5 Engine. Note Balanced Ailerons.

The diagram at Fig. 53 B shows the planes separated by a distance equal to the length of the chord. This is the usual spacing and while it is not the most efficient one it is the distance commonly used on account of structural reasons. There is still an opportunity for a conflict of the air currents between the surfaces but the area of disturbed air is considerably less than in the case where the gap was equal to but half the chord. When the gap between the planes is equal to the chord a biplane has an efficiency of but 80 per cent of a monoplane of the same wing area and aerofoil section.

It will be seen from the following table that the gaps tried varied progressively from 0.4 to 1.6 of the chord. The coefficients given are values by which the monoplane lift coefficients have to be multiplied in order to secure the biplane spacing values for the gaps given. The wing tested was was the form used on the Bleriot-XI, of a plan form that had a rounding wing tip and a shorter trailing edge than entering edge. The spread was about five times the chord. From the table it will be evident that the best arrangement or spacing of the biplane wings is determined by practical considerations. While there is an increase in efficiency as the gap increases there is a corresponding increase in the length and consequently the resistance of the plane spacing struts, the lifting and landing bracing wires and also the incidence wires. Practical considerations generally limit the gap or spacing so that it seldom exceeds the chord.

Effect of Stagger.—The efficiency of the biplane arrangement can be increased by staggering the planes, i. e., setting the entering edge of one plane some distance ahead of the entering edge of the other. A somewhat exaggerated stagger is shown at Fig. 53 C. The effect of moving the top plane forward is to increase the lift coefficient as well as obtaining a higher value of the lift-drift ratio. When the top plane is moved forward a distance equal to about two-fifths of the chord an increase in both lift and lift-drift coefficient of about 5 per cent is secured. This is equivalent to

TABLE IX

Corrections for Biplane Spacing

Ratio Gap / Chord	Lift Coefficient 6 Degrees	8 Degrees	10 Degrees
0.4	0.61	0.62	0.63
0.8	0.76	0.77	0.78
1.0	0.81	0.82	0.82
1.2	0.86	0.86	0.87
1.6	0.89	0.89	0.90

increasing the gap from 1.0 to 1.25 of the chord. Staggering the planes improves the efficiency of the upper plane because it reduces greatly the disturbed area between the planes. The planes are not always staggered forward; sometimes the lower plane may be set ahead of the upper one. The best effect is obtained by using the positive stagger rather than the negative as the range of vision of the occupants of the airplane is much better when the top plane is staggered forward and a more decided gain in efficiency is obtained. The views at Fig. 54 show two types of tractor biplanes. That at A shows a standard training machine which has a positive or front stagger, in this the upper plane is set forward of the lower plane. The design shown at B has a slight negative or back stagger as the lower plane is set somewhat ahead of the upper one.

Aerofoil Plan Forms.—It is not the purpose of a popular discussion of this character to consider the technical aspects of pressure distribution over the entire surface of the wings, but enough has been presented in a preceding consideration of this subject to show that the pressure is not uniform at all points on the wing. While considerable useful information may be secured if careful thought is given to the variations in pressure along the leading edge of the wing and at some distance back of this line on both upper and lower surfaces, experiments have shown that the values of the positive and suction lift over the central portion of the aerofoil or those parts near the fuselage were greater than at other portions of the wing and that the values of the positive and negative pressure became less near the wing tips.

The reason for this is that the air that is under pressure at that part of the wing near the tips has nothing to restrain its flowing out sideways and

inasmuch as this escape of air over the edges produces eddy currents, the value of the suction lift at the top will be likewise reduced. The reason that wings of reasonably high aspect ratio are more efficient than those forms of low aspect ratio is that the relative magnitude of the loss in lift due to the escape of air will be less in proportion to the total surface on a

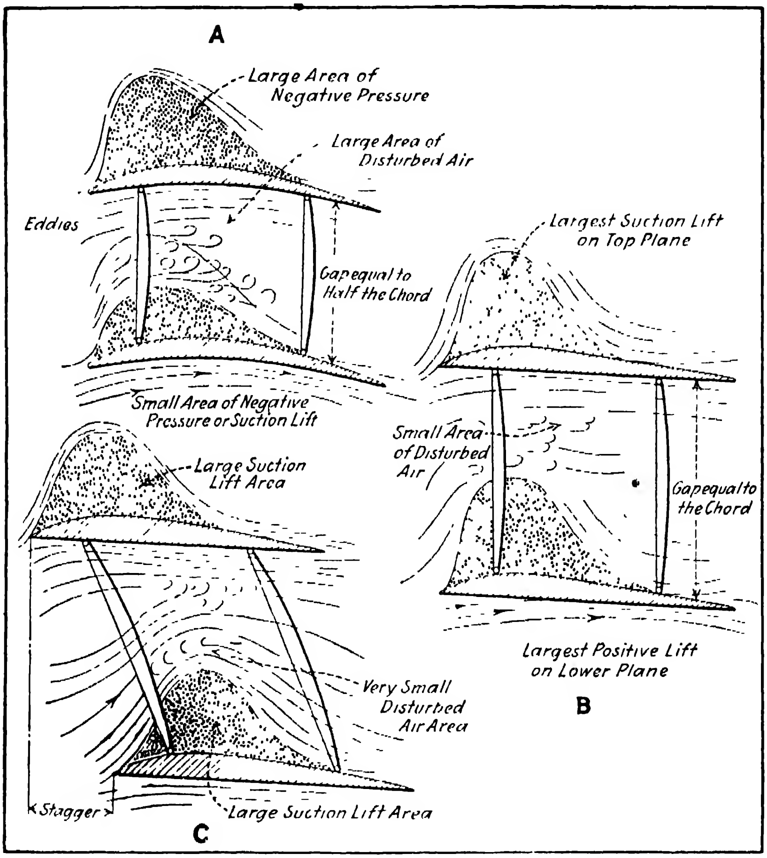


Fig. 53.—Diagrams Showing Effect of Biplane Spacing. A—With Gap Equal to Half the Chord, Note Interference and Eddies. B—With Gap Equal to Chord. C—Effect of Staggering Aerofoils.

wing of large span and small chord than it will be on an aerofoil of short span and long chord having the same area. This means that there is a gradual movement of the center of pressure from the leading to the trailing edge of the wing, and the center of pressure being nearer the leading edge at the central point of the wing and nearer the trailing edge at the wing tips.

Rectangular Plane Least Efficient.—The early forms of planes were built of a rectangular plan form as shown at Fig. 55 B. This was done because the influence of plan form on efficiency was not clearly defined and because it was a very easy form of wing to build, calling for a very simple framework, and, in fact, the single surface aerofoils of early days were not adapted to use the wing frame skeletons that are now available

since the double surface aerofoils became universally used. The rectangular plan form is less efficient aerodynamically than the later forms even on those wings having a high aspect ratio. The form of wing shown at Fig. 55 A is more efficient than the simpler rectangular form shown below it, as this gives an increase in total effective lift with a marked reduction in resistance or drift and at the same time there is no sacrifice of any of the constructional features making for strength, stability or ease of building.

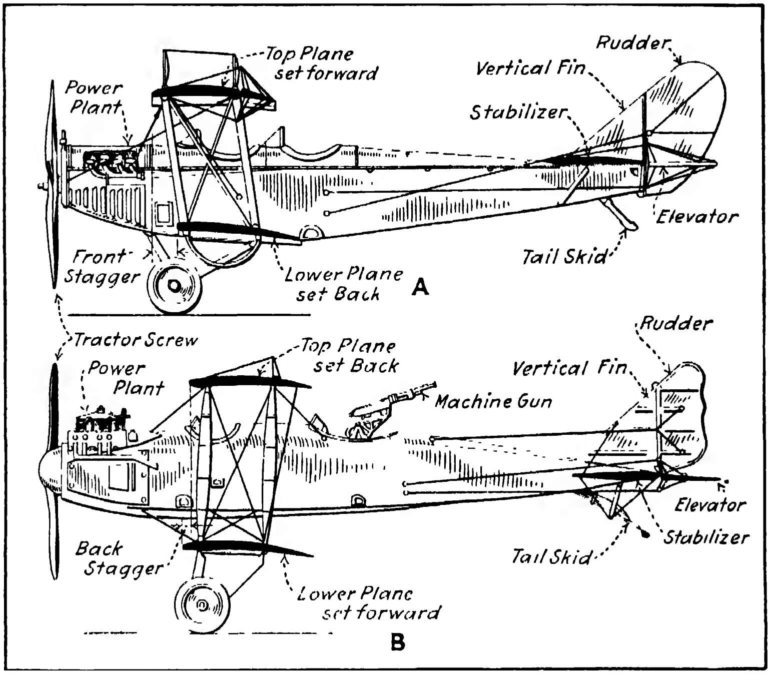


Fig. 54.—Typical Tractor Biplanes of Obsolescent Design Showing Positive or Forward Stagger at A and Negative or Back Stagger at B.

Securing Uniform Pressure Distribution.—In order to secure a reasonably uniform pressure distribution it has been stated that an ideal plan form would be one consisting of two triangles having their bases joined at the central section, the apex of each triangle representing a wing tip. This form of wing, which is shown at Fig. 56 A, would offer certain structural disadvantages, but even with the forms of wings generally used today there would be a marked improvement in efficiency if a form such as shown at Fig. 56 B were used in which the wings are widest or have the greatest chord at the center and gradually tapering away to small chord dimensions at the tips. The disadvantage in wing form of either of the types A or B, Fig. 56, is that there would necessarily be a grading down of the total depth or camber of the section to correspond to the lessened chord. Lanchester, in experimenting with wing plan forms, suggested the parabolic plan forms shown at Fig. 56 C and experiments have demonstrated that this would yield very good results that would be more satisfactory than those obtained with the rectangular shape first used.

The plan form and sections of the wings of birds have been previously considered, but it is not always possible to select the best type of aerofoil by their wing section, neither is it possible or desirable to approximate their wing plan in making airplanes. The plan view given of a soaring bird, the albatross which has a wing spread of high aspect ratio, would

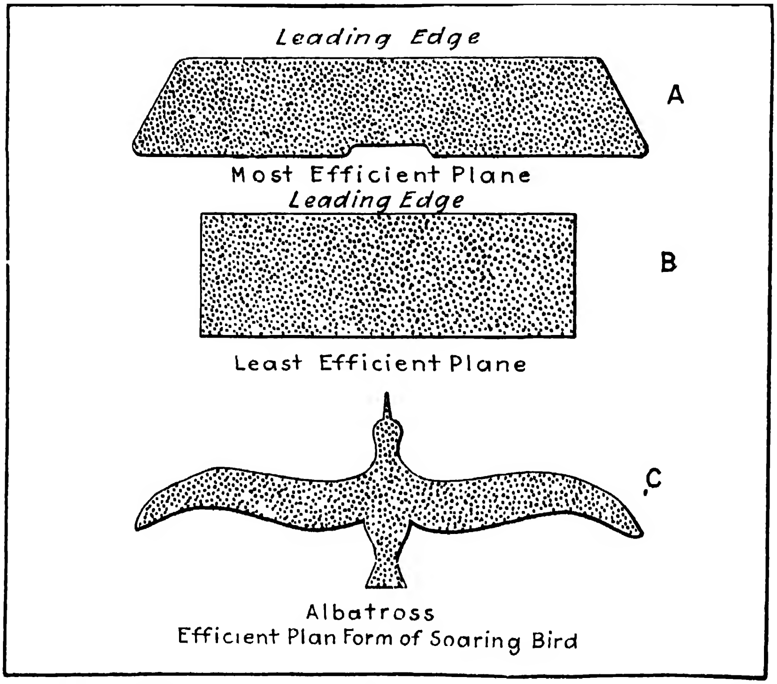


Fig. 55.—Diagram Showing Efficient Wing Plan and how it Approximates Bird Wing Plan Form to Some Extent.

be difficult to duplicate in an airplane wing on account of structural considerations. Two forms of wings that have been patterned with the object of securing greater efficiency than with the regular rectangular form are shown at Fig. 56. That sketched at D is the wing plan of the Bleriot monoplane, while that at E is the German Taube wing. Some similarity between this wing plan and that of the bird is evident, as a portion of the wings of the albatross near the tips has a decided "sweep back," or retreat, which is also seen in the Taube wing plan.

The aspect ratio of the wings of the albatross is about 14, meaning that the wing span is approximately 14 times the chord. The average airplane will have an aspect ratio ranging from six to eight. The shapes of birds' wings, both as relates to the section and the plan view, are undoubtedly determined by other considerations besides those having to do only with aerodynamical efficiency. It is evident that the habits and mode of flying of the bird have a material bearing on the wing plan. It may be said, however, that birds which in their soaring more nearly approximate the airplane have wing plans that would no doubt be satisfactory on the soaring machine if constructional difficulties did not intervene to make their practical application of somewhat dubious value.

The experiments of Professor Alexander Klemin with the wing model of the Edo flying boat have been previously mentioned.

The model used for the wind tunnel tests was a semi-span airfoil 25 inches long, with a chord of 6.6 inches. Half the span with a protecting disk was used, so that the largest possible model could be inserted in the tunnel. Ten capillary brass tubes of 1/32 inch internal diameter were let into the wing, and from small holes in these tubes the pressures on the upper and lower surfaces of the wind model were measured. Ten holes in

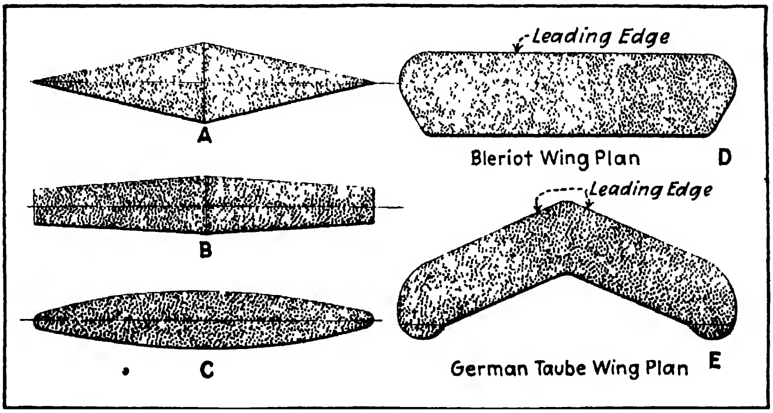


Fig. 56.—Theoretical Plane Forms to Secure Uniform Pressure Distribution at A, B, and C. Actual Plane Forms at D and E.

each tube on each surface gave a total of 200 holes at which observations were made. The pressures were measured with the Krell type gauge as the difference between the pressure at the wing and a side plate in the tunnel. The charts at Fig. 57 show lines of equal pressure across the span at angles of incidence corresponding to diving, high and low speeds. While the pressure varies in value at various parts of the wing, one usually takes an average of the different pressures and considers it as evenly distributed over the area in determining wing loading. Of course, in designing the structure the actual loading at various points must be considered.

Wood and Fabric Wing Construction.—Having considered at some length the aerodynamical properties of airplane wings and aerofoil sections, we will now proceed to discuss the wing structure from the practical viewpoint of the airplane constructor rather than that of the designer. As will be evident from the illustrations at Fig. 58 the wing skeleton before covering is a framework consisting of two longitudinal spars which are joined together by equally spaced ribs running from the leading edge to the trailing edge of the wing. The section of the aerofoil is always greatest at the front spar because most of the lift occurs near the leading edge. By employing spacing strips of the proper curvature it is, of course, possible to obtain ribs of any section, and it is the degree of camber given the ribs that determines the lifting properties of the wings when the framework has been covered.

The ribs are built up of narrow strips of wood about an inch wide and a quarter-inch thick, which are placed at the top and bottom of the curved

central rib member of plywood as shown at Fig. 59 that determines the camber of the aerofoil. The front ends of these strips are connected to a small moulding or leading edge spar that is termed the "nose" of the wing. The various ribs are tied together by light round wooden rods that extend from one end of the wing to the other. Another method of construction is the built up web as shown at Fig. 60. All portions of the wing structure are glued and screwed together, so that while a large number of individual pieces are employed in the wing frame the methods of joining them together are so secure that the completed structure has surprising strength for its weight. A textile fabric is stretched tightly over the wing frame and is fastened to both upper and lower surfaces of the ribs and spars.

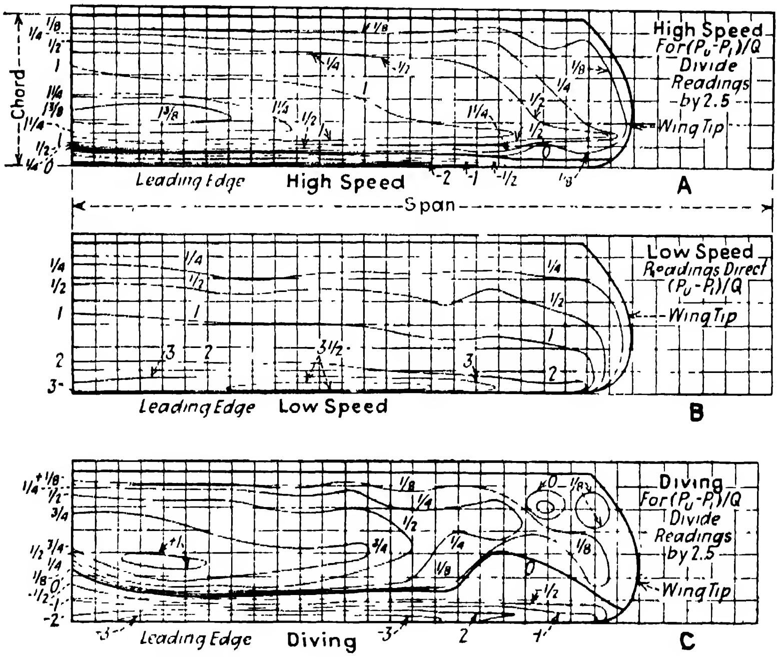


Fig. 57.—Diagrams Showing Lines of Equal Pressure across the Span of a Monoplane Wing. A—Pressure Distribution at High Speed. B—Pressure Lines at Low Speed. C—Pressure Lines at Diving Speed.

The leading edge is sometimes given a positive curvature by using a thin veneer of wood so as to give the cloth a definite form at the entering edge of the wing and in some constructions plywood has been employed for wing covering instead of fabric. (See Fig. 28 A and B, Chapter 4.) Wire bracing is extensively used inside of the wing to stiffen it. The tie wires join the front and rear spars and are of great value in stiffening the wing structure. The rear spar carries only a relatively small percentage of the total load of the wing, and for that reason is usually considerably smaller in section than the front spar. Wing spars may be made of either ash or spruce, and experiments that are now being made have demonstrated that metals such as duralumin may be used advantageously for this purpose. The ribs are usually made of poplar or spruce, though in some cases

mahogany has been employed. Spars may be a built-up or box section or they made be made from one piece, hollowed out to form an I section at various points and thus reduce weight without greatly sacrificing structural strength. As will be seen by referring to Figs. 59 and 60, the central rib member can be made of plywood with various forms of cut-outs to lighten the structure or the webs may be built up entirely of vertical or diagonal strips or a combination of the two, sometimes supplemented by diagonal bracing wires.

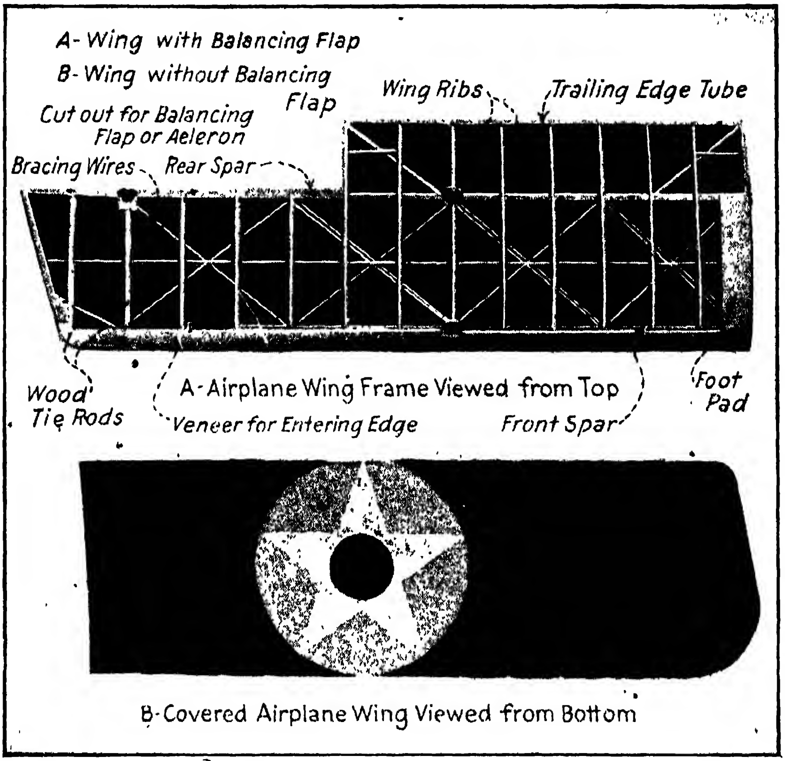


Fig. 58.—Typical Airplane Wing Skeleton and Appearance after it is Covered with Fabric.

An example of extremely light and strong wing construction of wood was used in the Navy N. C. planes. The rib is a truss designed like a bridge consisting of continuous cap strips of spruce, corresponding to the upper and lower chords of a bridge truss, tied together by an internal web system of vertical or diagonal pieces of spruce. The ribs are 12 feet long but only weigh 26 ounces each. On test these ribs were required to carry a proof load of 450 pounds of sand for 24 hours without damage. An interesting detail of the wing construction is the hinged leading edge which encloses the control cables to the ailerons or wing flaps. This eliminates the air resistance of these cables, but at the same time they are accessible for inspection by merely swinging up the leading edge on its hinges. The wings are arranged as a biplane with the necessary struts and wires to give

girder strength. For lightness the struts are made up as a spruce box, but to decrease resistance this square portion is enclosed in a fish-shaped fairing or "streamline" or stiff fiber. To reduce any tendency of the struts to bow under load, the middle points are connected with a steel cable. The diagonal bracing between wings is by steel cables in pairs. These cables are arranged to lie one behind the other with a spruce batten between to reduce air resistance.

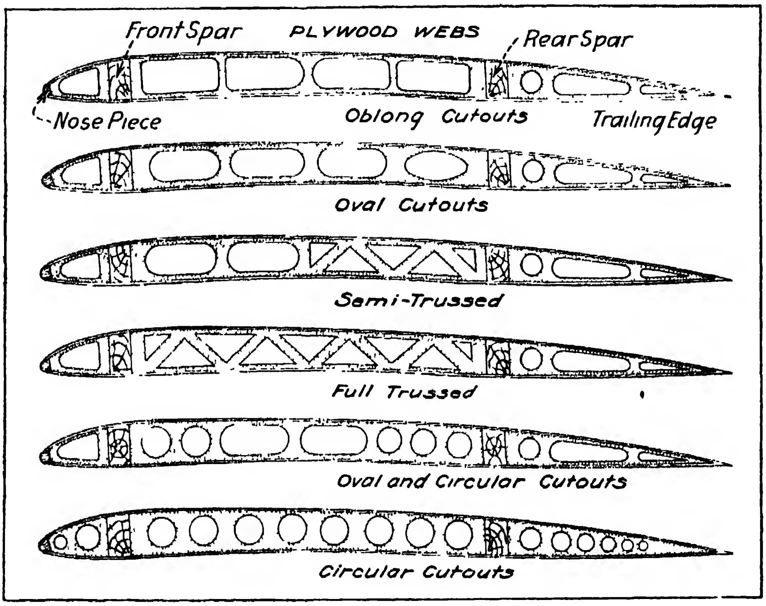


Fig. 59.—Wing Ribs with Plywood Webs Showing Various Methods Employed of Lightening the Ribs.

The metal fittings where struts and wires are fastened to the wings presented a serious problem. The forces to be taken care of were so large that it was necessary to abandon the usual methods of the airplane builder and adopt those of the bridge designer. All forces acting at a point pass through a common center. In this case, as in a pin bridge, the forces are all applied to a large hollow bolt at the center of the wing beam. In the design of the metal fittings to reduce the amount of metal needed, it was decided to employ a special alloy steel of 150,000 pounds per square inch tensile strength. To increase bearing areas, bolts and pins are made of large diameter but hollow.

Glue for Laminated Construction.—The British and German aircraft builders have used a type of casein glue composed usually of casein, slaked lime, caustic soda, sodium fluoride and paraffin oil, the three latter ingredients being used in small percentage. Contemporaneously American aircraft plants have been experimenting with types of casein glue for plywood construction produced in this country. Commander Richardson, U. S. N. states that the Bureau gave encouragement to experiments along this line and took up with the Forest Products Laboratory and the manu-

facturers the subject of the utilization of casein glue for strength parts of airplane construction. Through some intensive work, these glues were soon developed to such an extent that three were placed on the market by individual manufacturers in a form ready for use. These products were all thoroughly tested by the Forest Products Laboratory and found to give results which indicated their superiority over hide glue. The art of employing these glues in aircraft construction was developed with great rapidity. One of the prime requisites was the use of a power mixer for the thorough incorporation of the glue with the aqueous medium. The uniformly high strength of joints made with this glue soon indicated the

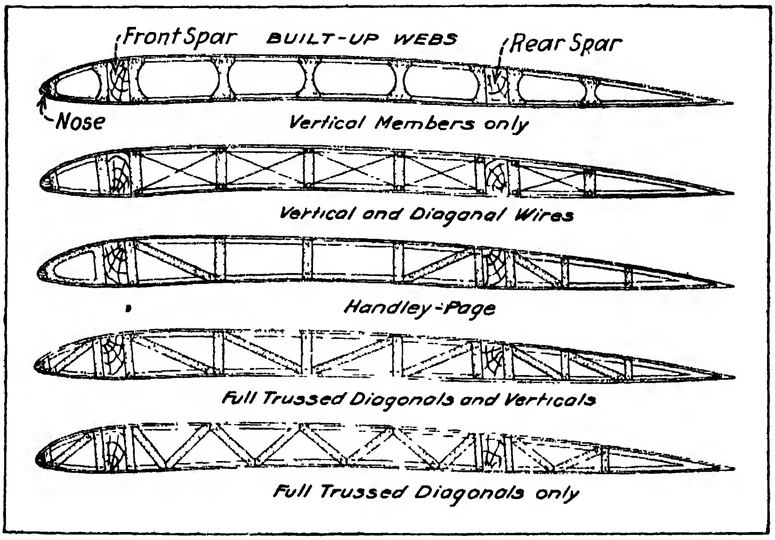


Fig. 60.—Built-Up Webs Showing Methods of Trussing Employed in Wing Rib Construction.

value of using it almost exclusively in place of hide glue and instructions along this line were sent to all naval contractors together with information in regard to using this new type of cold glue.

Casein glue used in this country is prepared from the solid part of skimmed milk. After it has been precipitated by acids or bacteria the casein is pressed, broken into small particles, trayed, dried, ground and bolted. The complete removal of fats is essential in casein that is to be used for glue. Adding a small percentage of hydrated lime forms calcium caseinate, an insoluble compound. Although this tends to harden the glue, it reduces the adhesive power and is very destructive to edged tools. Casein glue sets partly by evaporation and partly by chemical action. Most casein glues are heavy and spread less readily by hand than does animal glue, but that now being made for the automobile-body trade has overcome this difficulty; when a glue-spreader is used, casein glue will cover a greater area than an equal amount of animal glue.

The uncertainty of getting a good joint with animal glue, because of variations of the temperature of the room and of the wood and the com-

position and freshness of the glue, is obviated in casein glue, which may be mixed at any time in the correct proportions, requires no further attention, yet retains its maximum sticking properties. It may be used at temperatures below freezing on cold wood and the pieces may be allowed to stand for 20 minutes before being clamped or screwed. It is highly water-resistant; when applied to a three-ply panel the glue can be boiled without the plies separating. Heat does not weaken the glue but, on the contrary, strengthens it. One of the great advantages of its use in automotive applications such as automobile bodies and airplane fuselage and wing construction is the fact that it is quickly and easily prepared and thereafter needs no further attention; any portion that is left over at night is poured into the new mix the following morning.

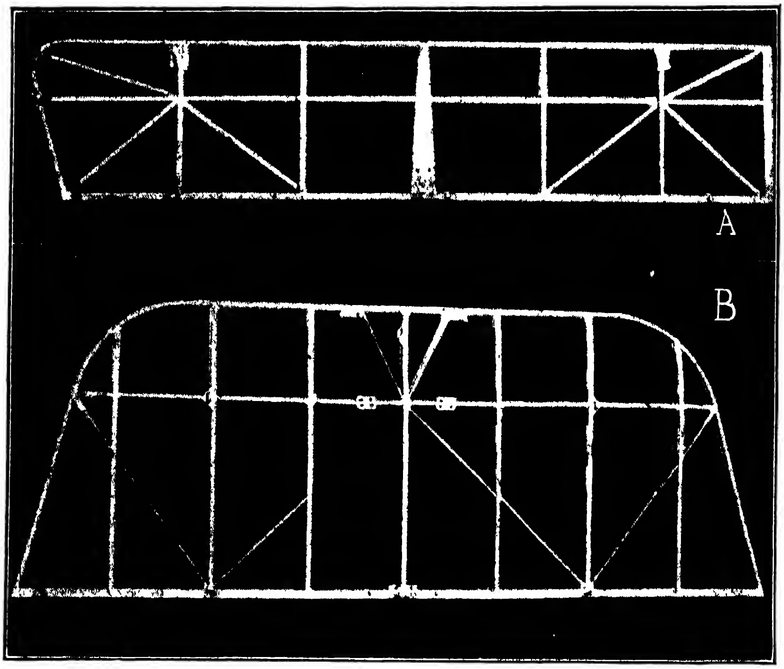


Fig. 61.—Skeleton Structure of Aileron or Balancing Flap at A (above) and of Stabilizer at B (below).

Properties of Wood Glue.—Glue forms a very important item among the materials that enter into the construction of airplanes and is also extensively used in building bodies for automobiles. To a great extent it is employed in the manufacture of plywood. In each of these lines of application the glue is exposed to atmospheric influences and the requirements made upon it therefore are materially different from those that must be met in the manufacture of furniture, wood patterns and other older lines of industry in which glue long has been used. These new requirements resulted in considerable technical development and research on glues during and after the war, and a prominent part in this work was taken by the Forest Products Laboratory of Madison, Wisconsin, which has recently issued a leaflet briefly reviewing the present status of glue technology. This

material is undoubtedly of interest to woodworkers and aircraft engineers and is reproduced herewith:

The glues that are adapted for gluing wood may conveniently be divided into five classes as follows:

1. Animal glues, which are made from the hides, hoofs, horns, bones and fleshings of animals, mostly cattle. These glues come in dry form and must be mixed with water and melted.

2. Casein glues, which are made from casein, lime and certain other chemical ingredients. They are commonly sold in prepared form, requiring only the addition of water, but may be mixed by the addition of the separate materials to the water.

3. Vegetable glues, which are made from starch, usually cassava starch, and sold in powdered form. They may be mixed cold with water and alkali, but heat is commonly used in their preparation.

4. Blood-albumen glues, which are made from soluble blood albumen, a product recovered from the blood of animals. These glues must be mixed from the separate ingredients just before use, since they deteriorate rapidly on standing.

5. Liquid glues, which are commonly made from the heads, skins, bones and swimming bladders of fish. Some liquid glues are made from animal glue and other material. They come in prepared form ready for immediate use.

Vegetable Glues Cheapest.—Vegetable glues are the cheapest kind, normally ranging in price from about 7 to 11 cents per pound. Prepared casein glues may range in price from 12 to 24 cents, different grades of animal glue from 12 to 30 cents, and dried albumen, suitable for making glue, from 16 to 38 cents per pound. Animal glue, frequently referred to as "hot glue," has been in use a long time and is familiar to all woodworkers. The principal desirable properties of animal glue are its great strength and reliability in the higher grades, its free-flowing consistency, and the fact that it does not stain wood. So far no glue has been found by the woodworking industry to be as suitable as animal glue for hand spreading on irregularly shaped joints, although a cheaper glue would be very desirable. The price of animal glue is the chief factor which limits its use. The fact that it is not highly water resistant is occasionally a drawback.

Casein glue has been used commercially for a much shorter time than animal glue, and its possibilities and limitations are not so well known. It has sufficient strength for either veneer or joint work. It is used cold, and when properly mixed it can be spread with a brush. The property most featured is its high water resistance, which makes it suitable for gluing articles to be used under moist conditions. Not all casein glues are water resistant, however; there are some on the market which are made to compete with vegetable glue and for which no great water resistance is claimed. Among the disadvantages of casein glues are their tendency to stain thin veneer and the relatively short working life of some kinds. It is claimed that this trouble has been overcome to a certain extent in some glues. They are somewhat harder on tools than animal and vegetable glues. Possibly this objection can be overcome by altering formulas or by using different steel in the tools.

COMPARISON OF USES AND CHARACTERISTICS OF VARIOUS GLUES

Point of comparison	Animal glue	Casein glue	Vegetable glue	Blood glue	Liquid glue
Source of principal ingredient	Animal hides, bones, etc.	Casein from milk	Starch, generally cassava	Soluble dried blood	Animal glue, or skins, bones, etc., of fish
Spread*					
Extremes reported	20 to 50	30 to 80	35 to 70	30 to 100	No data
Common range	25 to 35	35 to 55	35 to 55		
Mixing	Soaked in water then melted	Mixed cold	Mixed with alkali and water, with or without heat; can be made without alkali	Mixed cold	Requires no preparation
Application	Applied warm with brush or mechanical spreader	Applied cold with brush or mechanical spreader	Applied cold with mechanical spreader	Applied cold by hand or with mechanical spreader	Applied cold or warm, usually by hand
Temperature of press	Cold: hot cauls frequently used	Cold	Cold	Hot or cold, depending on formula used	Cold
Strength (block shear test)	High grade; have greater shear strength than strongest American woods; medium grades slighfly lower	Similar to medium grade animal glue	Similar to medium grade animal glue	Similar to or slightly less than medium grade animal glue	Good grades similar to medium grade animal glue; some brands very weak
Water resistance	Naturally low, but can be increased by chemical treatment	High or low, as required	Low	High	Low
Staining	Does not stain	Stains wood of some species	If mixed with caustic soda, stains wood of some species	Does not stain, but the glue is very dark and may show through thin veneer	Does not stain
Uses in woodworking	High grade, where a strong joint is desired; low grade sometimes used for veneering, especially where it is desired to prevent staining	Mainly where water resistance is desired in veneered or joint work	To some extent for joint work, but mainly in veneered work where good strength at low cost is desired	Almost entirely for water resistant plywood for aircraft or automobiles and for articles to be molded after boiling water	Mainly for repair work and gluing small articles by hand

* Expressed in square feet of single glue line per pound of dry glue for veneer work.

Vegetable glues have found wide use in recent years because they are cheap, can be used cold, and remain in good working condition free from decomposition for many days. They are extremely viscous, and it is not practicable to spread them by hand. Their lack of water resistance and the fact that they usually cause staining in thin fancy veneer are factors limiting their use. They set relatively slowly and for this reason are not so well adapted for joint work. Vegetable glues have been studied and developed almost entirely by private initiative, and there has been much litigation over patent rights during the past few years.

Blood-albumen glue has shown notably high resistance to moisture, especially in the boiling test. This makes it particularly suitable for gluing plywood which is later to be softened in hot water and molded. The production of molded plywood articles has been very limited, but it offers a good field for future development.

In the past the chief drawback to the use of blood glues has been the necessity for hot pressing, but recent tests have shown that a highly water resistant blood glue may be developed which can be cold pressed successfully. Liquid glues are, in general, similar in properties to animal glue. Some brands are quite equal in strength to good joint glues, but other brands are very weak and unreliable. Their great advantage is that they come in prepared form, ready for immediate use. This makes them particularly suitable for patch work and small gluing jobs. The factors which limit their use are their high price, their lack of water resistance, and the difficulty in distinguishing between good and poor brands. Generally speaking, present vegetable and blood-albumen glues are veneer glues, while animal and casein glues are used both as veneer and as joint glues. As between animal and casein glue for joint work, if freedom from staining is important animal glue is preferable; if water resistance is of importance then a casein glue should be selected. Because of the necessity of heat in the preparation and use of animal glue, the casein cold glue will probably be favored if both glues are otherwise equally well adapted.

Tests of Plywood Ribs.—Tests made by the Forest Products Laboratory for the Bureau of Aircraft Production have demonstrated that for chord lengths up to 75 inches, which, with an R. A. F. 15 section, would give a maximum depth of about 4½ inches, the type of construction which employs spruce cap strips, and a plywood web, suitably lightened by holes, is fully as efficient and strong as any built up or trussed rib, and in addition is more reliable and easier to construct than these types. That there is a limit, however, beyond which the trussed construction is superior to the plywood, is obvious, but only more extended experimentation can determine what this limit is. In the webs of plywood ribs two types of cutouts are used, the circular and the elongate; the latter may be oval or often nearly rectangular, with a length two or three times its depth. Since the vertical members of the web serve to carry compression and horizontal shear, and to prevent buckling of the web as a whole, it is usually best to have the grain of the face plies vertical. This is an illustration of the principle that the grain of the outside plies should be in the direction of a column load. Furthermore, as a function of the web is to act with the

flange or capstrip in carrying both compression and bending, it is best to have the core, in which the grain runs parallel to the capstrip, form a large proportion of the total web. Where low density woods are used in both the faces and core, the ratio of core to total thickness should be about 1 to 2; and where high density faces are used with a low density core this ratio may increase to 2 to 3. Among the light woods, Spanish cedar has proved most satisfactory for rib construction; while in the heavier species, combinations of yellow birch or maple faces with basswood or poplar cores are most suitable. Within the range of chord length which have been tested the following thicknesses have been found to give good results: For Spanish cedar throughout, 1/40 inch faces and 1/16 inch core; for birch outside plies and poplar core, 1/55 inch faces and 1/13 inch core.

Weight and Thickness of Plywood.—One of the leading sources of supply of plywood is the Haskelite Manufacturing Corporation of Chicago and it is to this company that the writer is indebted for much of the information on this material. It is said that its product is the only plywood made with blood glue and by the hot plate process.

This company is in a position to furnish HASKELITE in any thickness from 1/16 inch up. The woods most commonly used are mahogany and birch. Panels can be furnished in any size up to 94 inches one way and any length desired in the second dimension. The largest panels they have ever made are 88 inches by 684 inches. Panels 72 inches by 192 inches are not uncommon.

With reference to weights, plywood weighs as follows:

1/16"	3-ply	HASKELITE	approximately	.22	lbs	per	sq.	ft.
3/32"	"	"	"	.29	"	"	"	"
1/8"	"	"	"	.34	"	"	"	"
3/16"	"	"	"	.58	"	"	"	"
1/4"	"	"	"	.64	"	"	"	"
5/16"	"	"	"	.88	"	"	"	"
3/8"	"	"	"	1.06	"	"	"	"

During the past year the Haskelite Manufacturing Corporation have made a great many two-ply panels for wing beams. These panels are made of both spruce and mahogany in 1/8 inch and 3/32 inch thickness. The panels were made up with the face ply 90 degrees to each other and 45 degrees to the edge. These panels average 6 inches to 12 inches in width and up to 22 feet in length.

Wing Covering Fabric.—The wing covering is a fine, closely woven linen or cotton and especial care is taken to secure both strength and lightness. The weight of airplane wing fabric generally used will vary from four to five ounces per square yard. Its tensile strength varies from about 75 pounds per inch width in the warp direction (i.e., those threads of a fabric that are stretched lengthwise in the loom when the material is woven) and of about 100 pounds per inch in the weft direction. The weft threads are shorter than the warp threads, as they are those that are carried back and forth by the shuttle in weaving. Owing to the greater strength of the fabric along the weft threads it is usually attached to the wing skeleton so that the warp threads run in the same direction as the ribs.

No matter how finely woven the fabric is, it is apparent that it cannot be made either air-tight or water-tight. It is also evident that it would be difficult to stretch the cloth covering and attach it to the ribs so it would be uniformly tight in all directions.

Why "Dope" Is Used for Wings.—The fabric is made air-tight and water-proof and is also stretched to a taut surface like a drum head by the use of chemical preparations called "dope" in the trade. Practically all of these are cellulose acetate dissolved in some solvent such as acetyl, ether or pyroxolin lacquer or acetone. A number of coats of this "dope" are given the wings and each is allowed to dry thoroughly before the next coating is applied. Owing to the highly volatile nature of the solvents used, this drying is fairly rapid. The first coat penetrates all the spaces between the threads and also penetrates the fibers of the threads themselves. As the drying proceeds the substance contracts and brings the threads more closely together. From four to five coats of "dope" are applied to the surface of the linen, the increase in weight due to the use of the "dope" being about one and one-half ounces per square yard. The "doping" is said to increase the strength of the fabric by about 20 per cent as well as tightening it. Tautness is aerodynamically essential to reduce the sag to certain limits, though with the materials now in use probably any surfaces deteriorating to a slackness sufficient to affect the aerodynamical properties of the machine seriously would have been condemned long before on their appearance. Another point which has been somewhat neglected is the great extent to which the strength of the wing structure is influenced by the tension of the doped fabric upon it. In general slackness of the dope will weaken the wing structure, but on the other hand too great tautness will lead to deformation or even fracture.

The protection of the fabric wing covering becomes of added importance on the flying boats on account of the great area involved and the expense and difficulty of renewal. At one time, wings had to be recovered very frequently, but with the Navy standard doping practice as described by Commander Richardson the fabric stands up under favorable conditions from 6 months to a year.

To cover the NC surfaces about 6,000 square feet of fabric has to be treated requiring over 200 gallons of dope. There are two types of dope in use at present by the Navy Department. These are known as cellulose nitrate and cellulose acetate dopes. The latter is produced from cotton treated with acetic anhydride and acetic acid, while the other is made in a manner similar to the production of gun cotton through the use of cotton treated with nitric and sulphuric acids. The acetyl or the nitrate group is taken up by the cellulose to make a new compound which is soluble in certain solvents. The treated cotton is then dissolved in solvents such as methyl, amyl, propyl, butyl or ethyl alcohol, acetone, etc., subsequently adding other non-solvent thinners such as benzol, alcohol or benzene. Different kinds of softeners and fire-resisting salts are then added to the dopes. These are usually high-boiling, slow-evaporating liquids. Diacetone alcohol is a representative of this class. Triphynyl phosphate is used for its fireproofing value. A small quantity of urea is sometimes used to prevent the acidity which may be caused over periods of storage.

U. S. Navy Doping Practice.—The present Navy practice in doping fabric is to apply first two coats of acetate dope because of its higher fire-resisting value and because of the fact that the acetyl radical present is ordinarily not injurious to fabric. There is then applied three coats of cellulose nitrate dope. A very taut surface is obtained. Naval gray enamel is then applied in one or two coats according to the wing surface to be treated. With this practice no difficulty has been experienced with scaling or cracking of the wing enamel. On the other hand, when five straight coats of acetate dope are used very serious scaling and cracking of the subsequently applied enamel will take place. The cellulose nitrate dope, moreover, is very much cheaper than the acetate dope, is readily available, has greater covering properties and gives greater tautness to the fabric.

The use of the wing enamel referred to has been a curious development which dates back to the examination of rudders on some planes that were in use in Florida several years ago. The fabric was found to be rotted in several places but in perfect condition where covered with the naval aircraft insignia paint. This indicated the value of the paint in shutting out the actinic rays of the sun. From that time on the Navy has used an anti-actinic wing enamel.

Extensive tests have been made by the Bureau on the use of so-called fireproof dopes which consist usually of cellulose nitrate in which there have been distributed fireproofing ingredients such as di-ammonium phosphate, calcium, magnesium and zinc chlorides and also tricresyl phosphate in various combinations. Good results were obtained with di-ammonium phosphate.

Light Proof Dope.—New types of dope have appeared in recent years under the name of pigmented dopes, first used by the British. These consist usually of highly plasticized nitrate dope in which pigments and softening materials are distributed and are used in place of varnish. The wearing value and fire-resisting properties, however, are not as high as the naval gray enamel now in use by us.

Considerable work has been done by representatives of the Bureau in factory control of conditions at contractors' plants. This work covered the heating arrangements, removal of evaporated solvents, control of humidity conditions, design of fabric covering rooms, methods of dope application and factory control in operation, studies of ventilation and hygiene. The latter is a matter of some importance as cases of so-called dope poisoning have in some instances been observed, generally in the form of eruptions on the arms of the workmen or the development of greatly swollen hands. By the elimination of all highly poisonous dope solvents such as tetra-chlora-ethane and the installation of suitable ventilation systems much of this trouble has been obviated. Through the development of emmolients hands and skin of the workmen have been protected from troublesome effects.

Besides protecting the fabric parts, it is necessary to protect the wooden members and their glue joints. Ordinary paint is fairly satisfactory but too heavy. The common varnishes and shellacs are not watertight enough. Through the early efforts of the Bureau co-operative work was done to develop a type of spar varnish that would give satisfactory results upon

hulls, wooden parts and wing surfaces of Naval aircraft. After this varnish had been developed and specifications issued, manufacturers soon learned the method of producing it and within a short period of time it was found on the market in great quantities and at a reasonable price. The base of the varnish is tung oil.

Effect of Light on Dope.—An account of a long series of researches carried out at the Royal Aircraft Establishment (Great Britain) on the causes of, and methods of preventing, deterioration in strength and tautness of linen airplane fabric, was given by Dr. F. W. Aston before the Royal Aeronautical Society.

At the beginning of the war little had been published concerning the functions and weathering properties of dope. It was known that on exposure the dope of doped fabric cracked sooner or later, and it seems to have been generally believed that deterioration of both strength and tautness was due to such cracking. As it was expressed at the time, "the dope cracked and let the weather get through to the fabric." Though more or less correct as regards tautness, which is a function of the dope layer principally, this idea is now known to be entirely wrong as regards strength, which is chiefly due to the fabric. Energies were, therefore, largely directed to the preparation of flexible varnishes which would prevent the cracking of the dope layer.

When opportunities of examining old machines became more frequent, it was noticed that at points where the dope was covered with an opaque layer of paint, such as the number on the tail and the identification disks on the wings, the fabric retained great strength, although the unpainted parts might tear like paper. This suggested that the real cause of the weakening was light, a conclusion since abundantly justified. The dopes with which these results were noted were made with tetrachlorethane. As that compound is decomposed by sunlight, it is quite possible that the real agents that destroyed the linen were the chlorine and the hydrochloric acid liberated. In time the action of light was seen to be more direct and fundamental. The abolition of the use of tetrachlorethane for other and better-known reasons made little if any difference in the rate of deterioration, and long before the real causes were discovered practical prevention was achieved by a pigmented varnish of a dark khaki shade. Experiments extending over three years confirmed the view that the deterioration in the strength of the doped or undoped linen fabric under ordinary service conditions is due to light and to light only, the effect of other agents such as heat, moisture, bacteria, molds, etc., being inappreciable in comparison. Visible light had little if any destructive effect, but in the direction of the shorter wave lengths there appeared to be no limit. As ozone and peroxide of hydrogen have long been suspected of being the principal agents in the deterioration, experiments were made in which oxygen and water were partially or wholly eliminated. It was concluded that the removal of oxygen from the atmosphere surrounding the fibers largely reduced but did not eliminate the destructive action of light, while the presence or absence of moisture did not seem to be important.

At the time when the investigation of the best method of protection was started, it was not thought possible to pigment a dope without spoiling it.

Experiments were, therefore, made with dyes, and out of about 150 soluble in dope half-a-dozen or so gave promising results, two blacks and one yellow affording practically perfect protection and not fading. Raftites containing only 1 per cent of such dyes gave a decrease in strength of less than 15 per cent over 12 months' continuous exposure. Had strength alone been of importance dyed dopes would have been advocated, but tautness was equally essential, and the possibility of its deterioration being also due to the action of light and therefore to be minimized by dyes was not realized. In addition Dr. Ramsbottom discovered that raftite, which contains no tetrachlorethane, could be successfully pigmented and that such pigmentation enormously improved the qualities of the dope as regards tautness.

A pigment used for protection in either a varnish or a dope must have a high extinction coefficient for actinic light, must be capable of being ground extremely fine, since a given weight of pigment will cover an area directly proportional to its fineness, and must be chemically inactive to any of the constituents of the medium. The natural oxide of iron known as ochre possesses all these properties to a notable degree, and in view of its cheapness and of the fact that with the addition of a little lamp black it yields a khaki shade, it is not surprising that its use as the main constituent of pigmented varnishes and dopes is almost universal. For tropical work aluminum has much to recommend it.

How Fabric Is Fastened.—The fabric is called upon to sustain a load of about 20 pounds per square foot at a flying speed of 70 miles per hour, so it is securely attached to the ribs. The method generally used is to tack through light strips of cane, wood or fabric tape which acts as a spacing member to prevent the tack heads from breaking the linen. A certain amount of the "dope" penetrating the linen will stick it to the ribs and in some cases a stitching of a flax cord is used to tie the fabric firmly to each wing rib at both upper and lower surfaces. Wings that have been tested to destruction demonstrate that this method of fastening is extremely strong, and the writer has seen wings that have been damaged in wrecks in which the main spar has fractured and yet the fabric will be held securely to the ribs. When the stitching is employed, the cord and knots on top and bottom of ribs are covered with narrow strips of fabric about two inches wide which is securely "doped" into place in order to provide a smooth covering and to lessen the skin friction. In order to give a smooth finish to the wing after doping it is sometimes smoothed down with sandpaper and a coat of spar varnish applied.

Metal Wings.—When using metal for airplane wing construction, one cannot copy existing wood and fabric design as structural arrangements best adapted to metal construction are not the best for wood. It is folly to attempt all metal construction and copy the conventional biplane design. If a modern monoplane design is chosen, all metal airplanes can be made lighter in proportion to the pay load than wood, wire and fabric biplane structures can.

No one has developed a positive or uniform way of inspecting wood. No one can take a piece of spruce spar and tell within 40 per cent what the piece will stand without breaking; the only way to tell is to break it.

When it breaks, its structure is entirely destroyed and, in a compression test, is splintered into many sharp penetrating pieces. The strength of a piece of metal is known within 5 per cent. Before it is put to the test, one can estimate easily just what a piece of metal will endure. Metal, therefore, is a much more easily inspected and dependable material for minimum-weight structures than wood, even when factors of safety many times

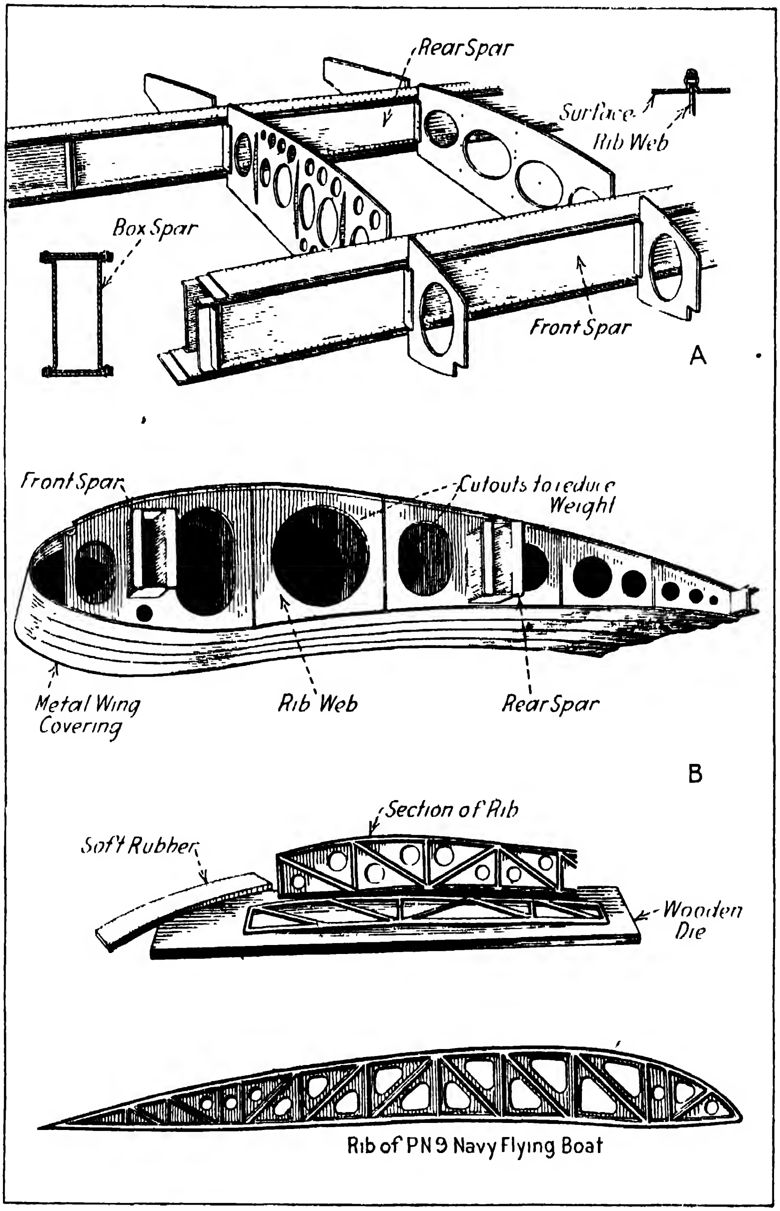


Fig. 62.—Methods of Metal Wing Rib Construction. A—Composite Structure Built from Pieces cut out of Duralumin Sheet. B—Wing Rib Stamped from Sheet Metal by Simple Wood Dies Used in Navy Experimental Work.

beyond the actual requirements are assumed. Lack of knowledge of the actual strength of any wooden piece is the reason for much unnecessary weight in wooden airplanes.

An interesting application of all metal wing construction that follows the design of wood construction to some extent is found on the Vickers-Wibault monoplane, an English design. As will be seen by referring to Fig. 62, the usual spar arrangement is followed, these being built up members of box section and ribs are used between them, cut from sheet duralumin which correspond to the plywood used in wooden ribs. The wing is of thick section and is of purely rectangular shape with the exception of that part cut away over the pilot's cockpit. The section, however, tapers appreciably in thickness toward both the wing tips and the center line from the point of the bracing strut attachments. This variation in thickness is so designed as to give a spar depth varying such that the strength of the beam is uniformly distributed according to the loading carried.

The simplicity of the wing structure is notable. The main spars are of box construction. The side members are flanged top and bottom and the top and bottom members are plain metal strips rivetted to the flanges. These members are double throughout. The ribs, which are compounded of three individual and separate pieces, are secured to the spars by means of vertical flanges rivetted to the sides at intervals. The ribs project above the normal profile and covering sheets which have flanged-up ridges are rivetted through these edges and the ribs, thus both faces of the rivets are exposed. Furthermore, the ribs do not extend to the leading edge, this being formed of a shaped strip of duralumin rivetted to the covering of the rest of the wing and forming a nose piece.

The ribs themselves consist of simple sheets of metal lightened and strengthened where necessary. Being made in three pieces, they are secured to the spars in the following manner: first, the forward section, rivetted to a flange on the side of the front spar, then the middle section rivetted to the corresponding flange the other side of the spar. This middle section is secured to a flange on the rear spar in a similar way and finally the rear section of the rib secured to the rear of the rear spar on a flange. Drag struts in the wing structure are of duralumin tube carried from stiff brackets rivetted to the main spars.

Navy Practice for Experimental Metal Ribs.—Metal construction reduces weight. That is one important advantage. Press construction reduces the number of parts with less assembly cost. The desirability of having satisfactory designs ready for the great manufacturers to start work upon immediately, in time of national emergency, is readily perceived. Having these ideas in mind, the aeronautical engineers of the Navy Department have endeavored to develop designs for naval airplanes adapted to the general shop processes of the large automobile builders. In following out this plane, a low-cost method for making pressings in sheet metal, which may be of interest to engineers in general, has been developed and put into use at the Naval Aircraft Factory and has been described by Commander R. D. Weyerbacher, U. S. N. in Automotive Industries.

The method may be briefly described as the use in a press of a single die with sheet rubber, in lieu of a second matched die. Of course, the use of rubber as a filler or forcer, in place of a liquid, in cases where hydraulic dies may be used, is not new, having been known and used in the art for many years. However, it is believed that the use of rubber to make such shapes as are illustrated at Fig. 62 B represents pioneer work. The wooden die used for making the section of an experimental airplane wing rib is shown, as well as a section formed by the process and the rubber used to press the metal into the mold or die. The rib used on the PN9 sidewalk wing panels is also shown. This is 54½ inches long and pressed of material .023 inches thick. The maximum ordinate is 11½ inches.

The method presents the following advantages:

1. A single die only is needed.
2. This die may be of wood, metal or other material, depending upon the amount of use it is to have.
3. The die may be made in the most reasonable of a number of ways, depending upon which is most applicable to the work in hand; it may be cast, it may be built up, or it may be machined from stock.
4. The die need be finished only to the tolerances and with a smoothness required in the complete article, i.e., no fitting of male and female dies is required.

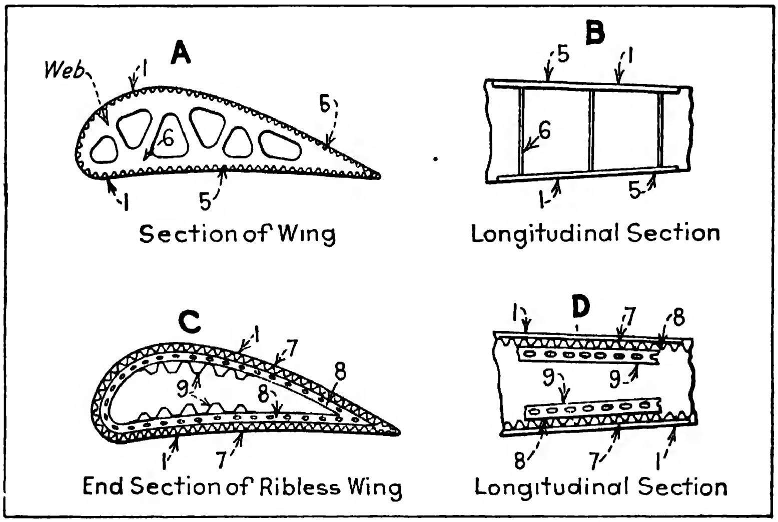


Fig. 63.—German Junkers Metal Wing Construction. A-B, Sections of Wing Using Webs or Ribs. C-D, Sections of Ribless Wing. Note Use of Corrugated Sheet for Covering.

Use of Corrugated Sheets.—In order to secure greater strength, instead of using plain surface sheets of duralumin as wing and fuselage covering, corrugated sheets have been employed by several manufacturers of all metal airplanes, notably Junkers in Germany and Stout in this country. The employment of corrugated metal construction in airplanes dates back twelve and possibly a few more years. In 1915, the German designer, Herr Hugo Junkers advocated the application of corrugated sheet metal to the

construction of all-metal airplane wings. Reprints from the Junkers patent show, in Fig. 63 A and B, the method of combining a flat outer skin with a corrugated reinforcement sheet and metal ribs to maintain the section, while in C and D, a ribless type of metal wing construction is shown, which involves the employment of multiply stiffening. Junkers planes were the first to employ corrugated metal construction in both wings and as a fuselage covering, in each case the inherent stiffness enabling considerable reductions in the extent of the internal structure.

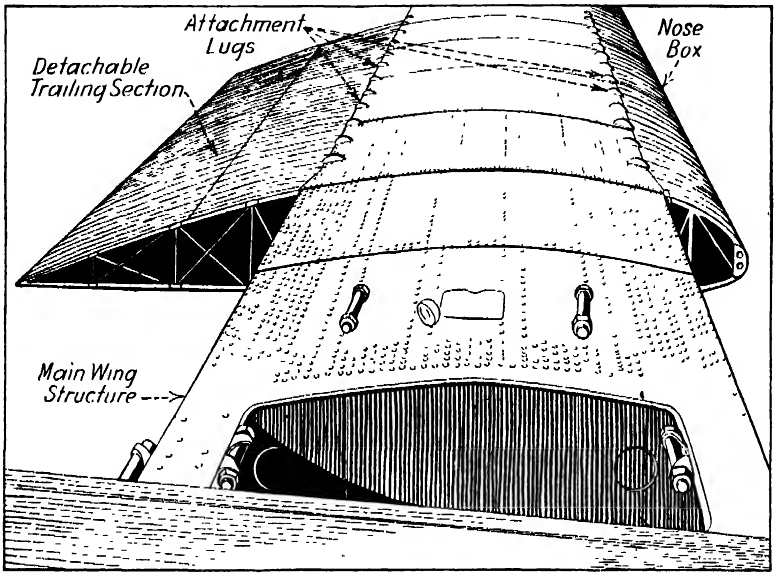


Fig. 64.—The Rohrbach Wing has Detachable Nose Box and Trailing Sections Fastened to Main Wing Structure. Duralumin is Used at All Points.

In a paper read before the S. A. E., Adolph Rohrbach, a German aeronautical engineer discussed the subject of all metal construction as applied to the Rohrbach flying boat monoplanes. He brought out the point that higher wing loadings are possible with metal structures and also described the construction of very large span monoplane wings by a sectional unit assembly plan. The following excerpts are taken from this interesting paper, the full context of which is available in the S. A. E. Journal for January, 1927, the official publication of the Society. Mr. Rohrbach is authority for the following:

"We endeavor to use the highest possible wing-loading and, correspondingly, to secure the highest power-loading. As is generally known, wing-loading means smaller bending and twisting moments of the wing, a shorter tail and smaller tailplanes and consequently less dead-weight, greater strength and endurance of the whole structure and lower building cost. The disadvantages of small wings are reduced ability to climb and higher take-off speed. To a certain extent both these disadvantages can be counterbalanced by a lower power-loading. Another drawback of too high a wing-loading is a relatively bad L/D or gross lift-thrust ratio of the whole airplane, because the parasite resistance cannot be reduced

below a certain limit and therefore this resistance becomes more and more predominant as the wing area is made smaller. Taking all this into account, it is a matter of compromise to select the best wing-loading for any special purpose. Everyone must make this compromise, but most constructors try to obtain the lowest possible landing-speed so as to have the advantage of greater maximum speed and lessen the influence of gusts. Neither with flying-boats nor with land airplanes have we had any bad experience from their comparatively very high wing-loading.

The following table shows, for example, the influence of alterations of the wing-loading in the case of a single-engine night-bombing airplane. In the case of this airplane, high speed and long range were more important than a high ceiling. Even in this case, where climb was not very important, it is useless to increase the wing-loading beyond 14 pounds per square foot.

INFLUENCE OF WING-LOADING ON WEIGHT AND PERFORMANCE

Details	Airplane A	Airplane B	Airplane C
Span, ft.	123	99	87
Wing-Loading, lb. per sq. ft	9.2	13.5	16.4
Power-Loading, lb. per hp.	21 4	20.4	19.0
Flying-Structure Weight, lb.	7,000	6,050	5,470
Flying Structure, per cent	35.3	32.2	31.1
Powerplant, per cent	18.9	19.8	20.9
Useful Load, lb.	9,100	9,100	8,450
Useful Load, per cent	45.8	48.0	48.0
Maximum Speed, m p.h.	117	125	132
Landing-Speed, m.p.h.	47	56	62
Service Ceiling, ft.	14,100	9,850	9,200
Range at Full Speed, miles	1,930	2,070	1,990

Mr. Rohrbach stated his company would build no more biplanes but build monoplanes only for all purposes. The art of constructing biplanes is relatively much more developed than that for the monoplane. Nevertheless, we have already obtained with the monoplane at least as good and often a much better performance than with the biplane. Apart from that the monoplane is more simple, strong and durable and therefore cheaper in every respect. Within a few years, there will be no chance for biplanes in competition with the then so much more refined monoplanes. I have often met people who argued that monoplanes must be less maneuverable than biplanes on account of their greater span. It is true that the moment of inertia of the plane is increased by the greater span, but the monoplane tail is longer, so that the lever arms of all control-surfaces are increased correspondingly. Apart from that, we have found that the amount of dihedral angle has much more influence on the lateral controllability than the moment of inertia.

Rohrbach Wing.—Since more than 8 years ago, the Rohrbach Company have developed the metal-covered wing. The two main problems are (*a*) light weight as a compromise with great strength and endurance and (*b*) easy maintenance and easy repair of the whole structure.

The stressed skin made out of flat plates, as used in shipbuilding, is their solution. Task (*b*) is fulfilled by the detachable nose and by rear

end-boxes, as shown in Fig. 64. Though the stressed-skin construction with flat plates is, in principle, most suited to obtain a high and rigid metal-covered wing, a very great amount of detail work was required before this type of wing construction could be mastered. A great number of tests were made since 1919 to determine the best form and arrangement of every detail member of these hollow box-girders.

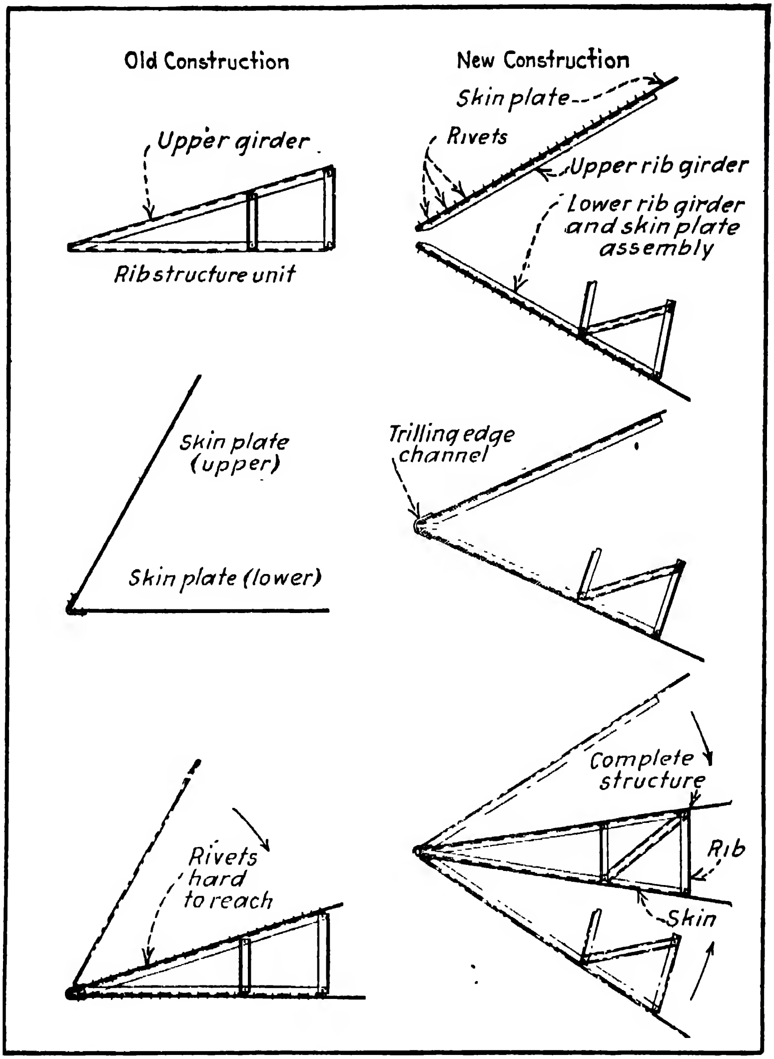


Fig. 65.—Principles of Construction Used in Rohrbach Control Surfaces to Facilitate Manufacture and Reduce Costs of All Metal Structures.

The wing consists of the hollow box-girder and nose and trailing end-boxes to complete the wing profile. The webs of the box girder are cut out of plates. The right shape of the cut-outs is obtained by following a plywood jig which is fixed on the plate. These cut-out plates are then held in the right position with the girder angle-profiles by jigs. On these jigs,

the angles are fixed to the girder plates by rivets or screws. The girder is then taken out of the jig and all the riveting is done by riveting-machines. The transverse walls are made in the same way as are the longitudinal girders. The assembling of the finished longitudinal girders with the transverse walls is done on a steel fundament.

The next process is the installation of the lower skin. After that, the girder is taken from its bed and the upper skin is riveted on. Most of the riveting seams between the separate plates of the upper and lower skin are made by riveting-machines. The assembling rivets which connect the skin with the girders and the transverse walls are riveted with pneumatic hammers. The steel fittings of the joint between the wing and the boat are riveted into the box girder on a special jig, which secures their proper position. All other steel fittings for the attachment of engine or of landing-gear struts, all bearings for the aileron control-rods and all bearings for nose end-boxes are also attached to the box girders, so that it is entirely finished and no more work need be done on this part. The nose end-boxes are assembled out of ribs and skin plates on a jig. This jig secures also the right position of the bearings by which they are attached to the box girder later on.

The building of plate-covered control-surfaces formerly required much hand-work and was very expensive. Fig. 65 shows how a simple alteration of the production method eliminated most of this hand-work, the result being that the building-time was reduced by 83 per cent. The left side of the drawing represents the original building-method, where small ribs and the upper and lower skin were connected by a great number of rivets that, for the most part, were very inaccessible. The cheap method is indicated by the drawings on the right side. First, the rib girders are riveted to the skin plates on riveting-machines. Then the two skins are connected by the trailing angle, also on riveting-machines. Last, a few rivets are riveted by hand to secure the upper rib-angle to the posts and the diagonals of the rib.

The Rohrbach subdivided wings, easily accessible for inspection and repair, are at present perhaps 10 or 20 per cent more costly to build than metal-frame wings with canvas covering. Very probably they will be as cheap as metal-frame canvas-covered wings within a short time; but, even if the manufacturer should not succeed in a further cost reduction, that type of wing can compete with the metal-frame canvas-wing because the canvas covering must be replaced at least once a year at a cost of about $4 to $5 per square meter (10.76 square feet) of surface while the metal skin is much more enduring.

The construction of metal airplanes requires a great number of special tools and jigs. To reduce the number of special tools, the Rohrbach Company have standardized duralumin profiles, riveting spaces, bolts, and the like. In no other industry is the cheapness of jigs so important as in the aircraft industry, with its frequent alterations of design.

One of the most important problems in connection with the use of duralumin in seaplanes is that of corrosion. The Rohrbach Company had great trouble in this respect but, with all the precautions which are now used, this difficulty seems to be overcome definitely. All profiles and con-

necting points must be accessible from both sides, so that they can be inspected and repainted easily. All plates, butt-straps and profiles are painted before being riveted together. The rivets are of the same alloy as the plates and profiles and are annealed at 510 degrees centigrade (950 degrees fahrenheit). Rivets that are annealed at a low temperature become corroded much more easily. A kind of black varnish has proved to be the best protective against corrosion. Great care is necessary when other metals are connected with duralumin. Bronze and copper are most dangerous because their electrical tension is very high and this destroys duralumin rapidly. The same difficulty exists with many kinds of chromium steels and also with stainless steel, which contains much nickel. The designer should endeavor to use, against duralumin, steel having a not too high electrical tension and all steel fittings should be isolated electrically by thick protective painting between the steel and the duralumin.

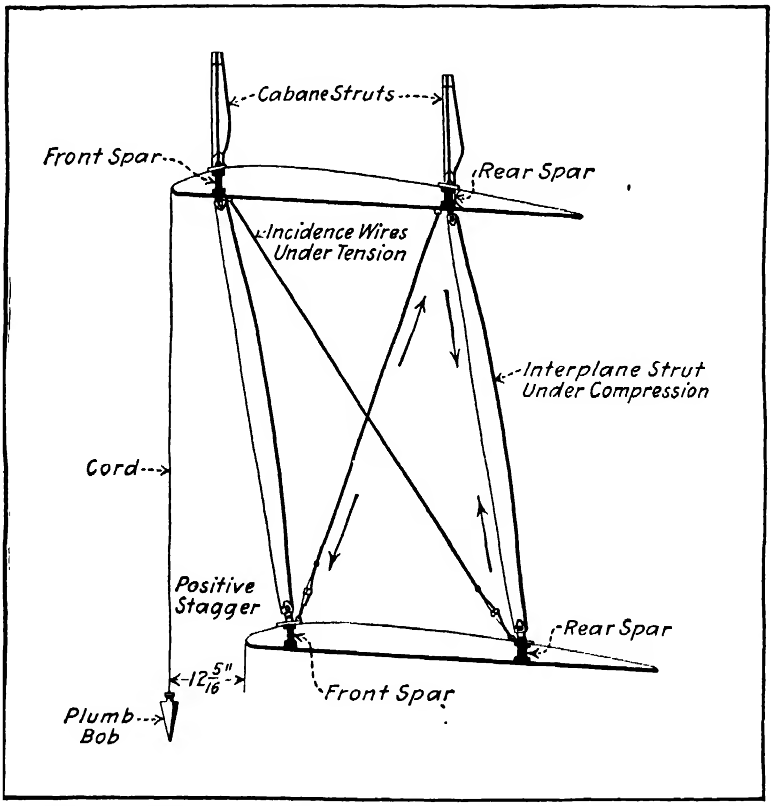


Fig. 66.—Diagram Showing the Use of Incidence Wires between Planes Mounted in Staggered Relation.

Airplane Wing Bracing.—Mention has been made previously of the strength obtained by the biplane arrangement of wings because a set of fitting surfaces are held together by tension wires passing in three dimensions, forming the assembly into a very light box girder. Referring to Fig. 66 it will be seen that wires are placed between each pair of struts or com-

pression members and that these are tension members which tend to bring the wing spars tightly against the struts of spacing members. One wire extends from the top rear spar to the bottom front spar. The other from the top front spar to the bottom rear spar. These wires are called "incidence" wires, as they keep the planes in the proper angular relation to each other.

One advantage of a biplane is that the wings can be completely assembled and braced up independently of the fuselage. This means that they can be handled as a unit and readily installed or removed. A typical wing section assembled on one side of the biplane fuselage is shown at Fig. 67. When the airplane is in flight the lift exerted on the wings will,

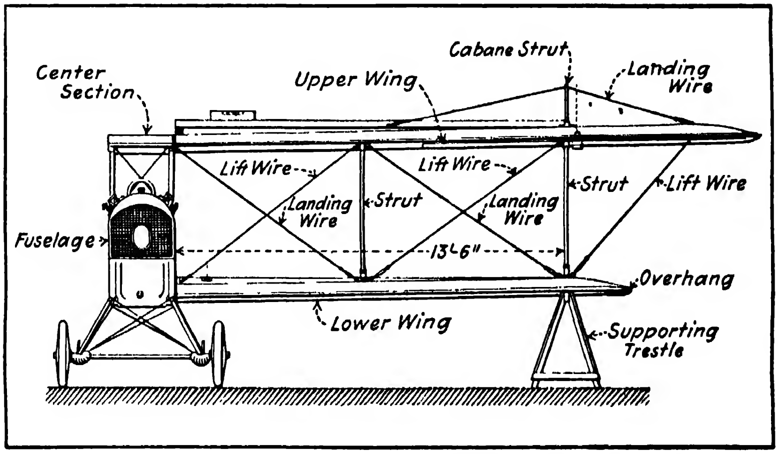


Fig. 67.—Diagram Showing how Braced Biplane Wing Assembly Forms a Complete Structure that may be Easily Assembled as a Unit to Biplane Fuselage.

of course, tend to force them up while the weight of the fuselage tends to force them down at the center. The result of this combined force is that the wings tend to fold up from the tips inward towards the fuselage. It will be evident that bracing wires are necessary to prevent this. The upward pull of the upper parts exerts a lift and puts some of the diagonal wires under a tension loading. The lift on the lower spars imposes a compression strain in the spacing struts between the planes. Under this condition the top spars are in compression and the lower ones under tension. When the machine is in flight the load is carried by only one set of wires which are, therefore, known as lifting wires. The opposing diagonal wires do not carry any load when the machine is in the air, but, however, when the machine alights and the wings lose their lifting effect the other set of wires is brought into play, and for this reason they are called landing wires. When the machine is in the air the flying wires are in tension or stretched while the landing wires are slack. When the machine is resting on the ground on its landing gear the conditions are reversed and the flying wires do not carry any load while the landing wires are in tension. When the machine is resting on the ground the top wing spars are in tension and the bottom wing spars are under compression. Obviously the spacing struts between the wings remain under compression all of the time.

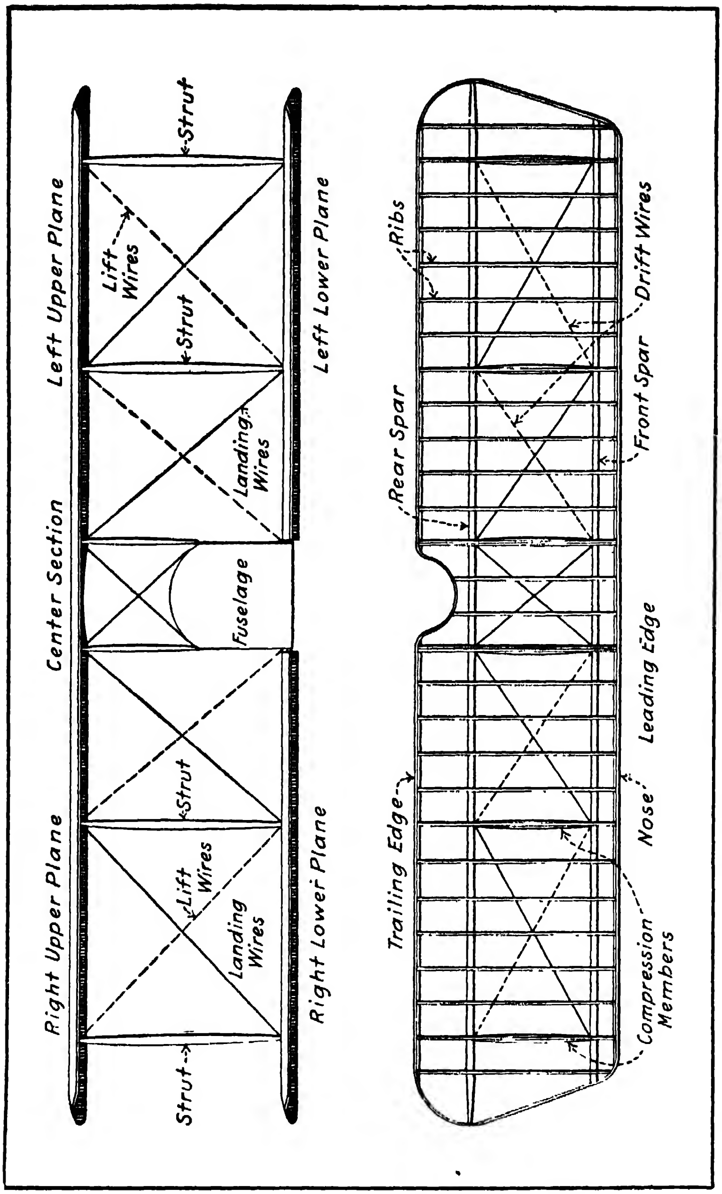
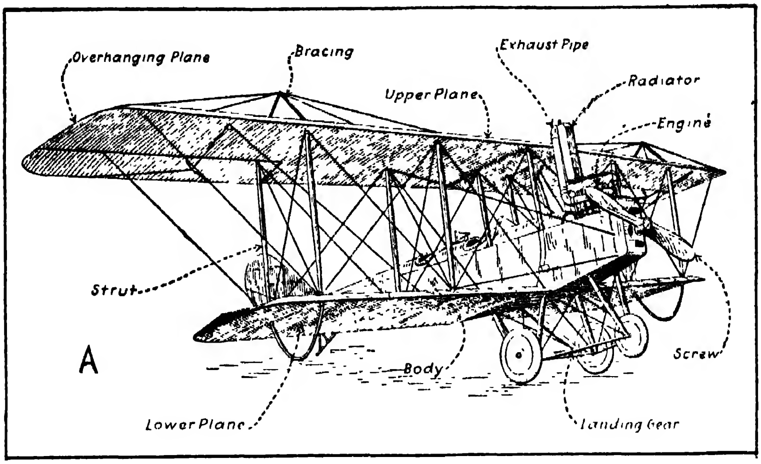
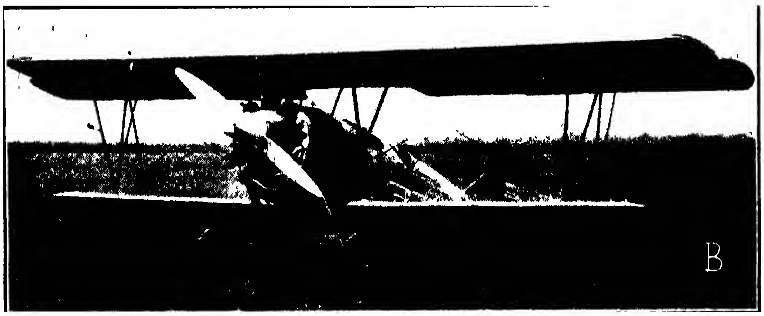


Fig. 68.—Diagrams Indicating the Arrangement of Lift and Landing Wires and Relation to Interplane Bracing Struts and also the Drift Wires and Compression Members in Airplane Wing Structure.

Loads on Airplane Wing Wires.—An airplane wing is not only subject to a lift reaction, but also a drift reaction. As the machine flies through the air the pressure of the air against the wings exerts a horizontal loading that tends to fold the wings backward at the same time that the lift reaction tends to fold them upward. Horizontal bracing wires are provided in the wings to prevent the rear spar from bending backward and are known as drift wires, while compression struts are placed between the front and rear spars to hold the front spar at the correct distance. In some airplanes special wires extend from the front end of the fuselage to both





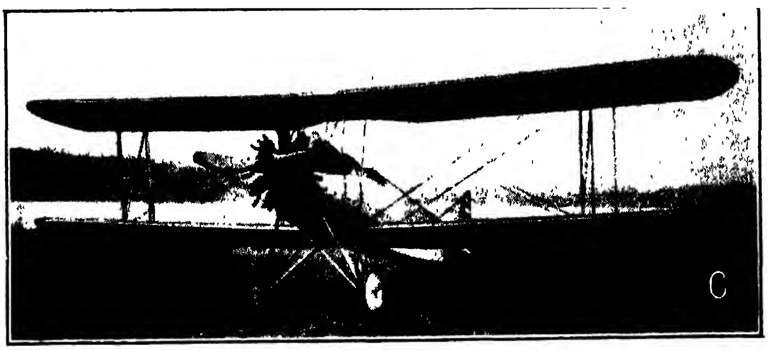


Fig. 69.—Three-quarter Front View of Early Biplane at A Showing Interplane Struts and Functions of Bracing Wires. B and C—Modern Designs Showing how Parasitic Resistance is Reduced by Using Fewer Struts and Wires. B Shows Whirlwind Motored Travel Air Biplane. C Shows Boeing Whirlwind Motored Training Biplane.

front and rear spars of the wings to take the drift reaction. These wires are clearly indicated in Fig. 69 A.

The bracing wires are called upon not only to resist the elementary forces considered, but while performing evolutions in the air they may be subjected to combination strains resulting from loads coming in different directions that cannot be computed accurately. It is therefore important that the bracing wires have a wide margin of safety over the actual requirements. It is also evident that one of the important items in connection

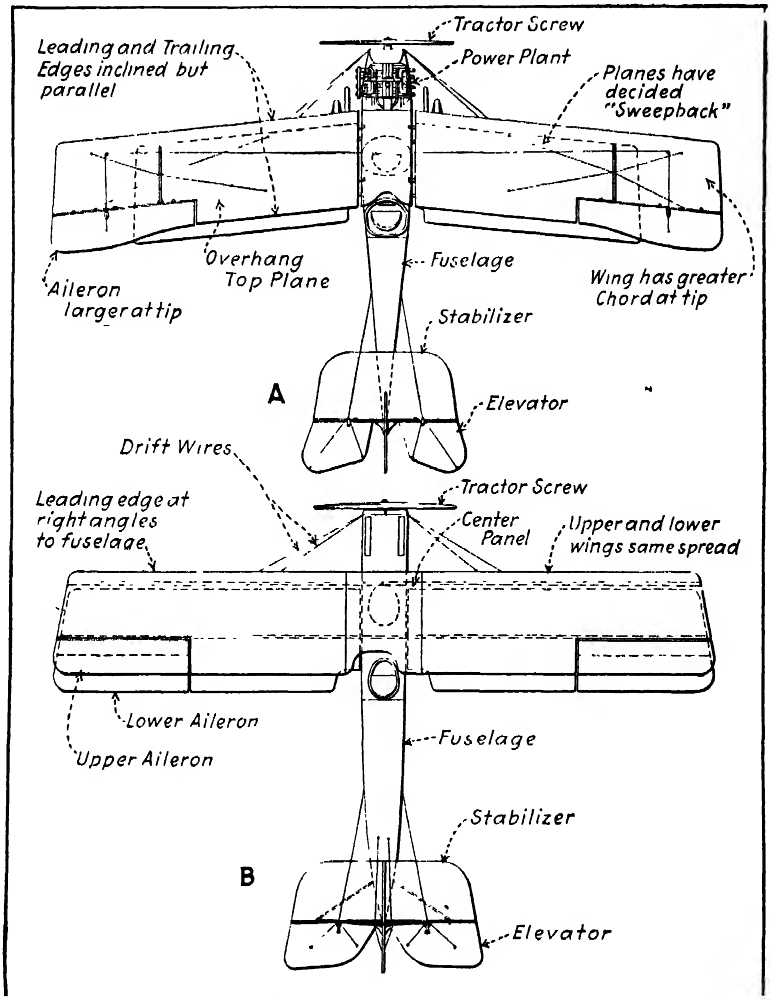


Fig. 70.—A Comparison between Two Accepted Types Showing how the Ideas of Designers Differ. Note that the Plane Shown at A has Upper Wings of Greater Spread than the Lower, while the Plane Shown at B has Wings of the Same Spread.

with airplane maintenance is to make sure that the bracing wires are always at the correct tension and that they are securely fastened and not frayed or weakened in any way. In order to prevent the bracing wires from rusting, those that are inside of the wing structure are painted or enameled,

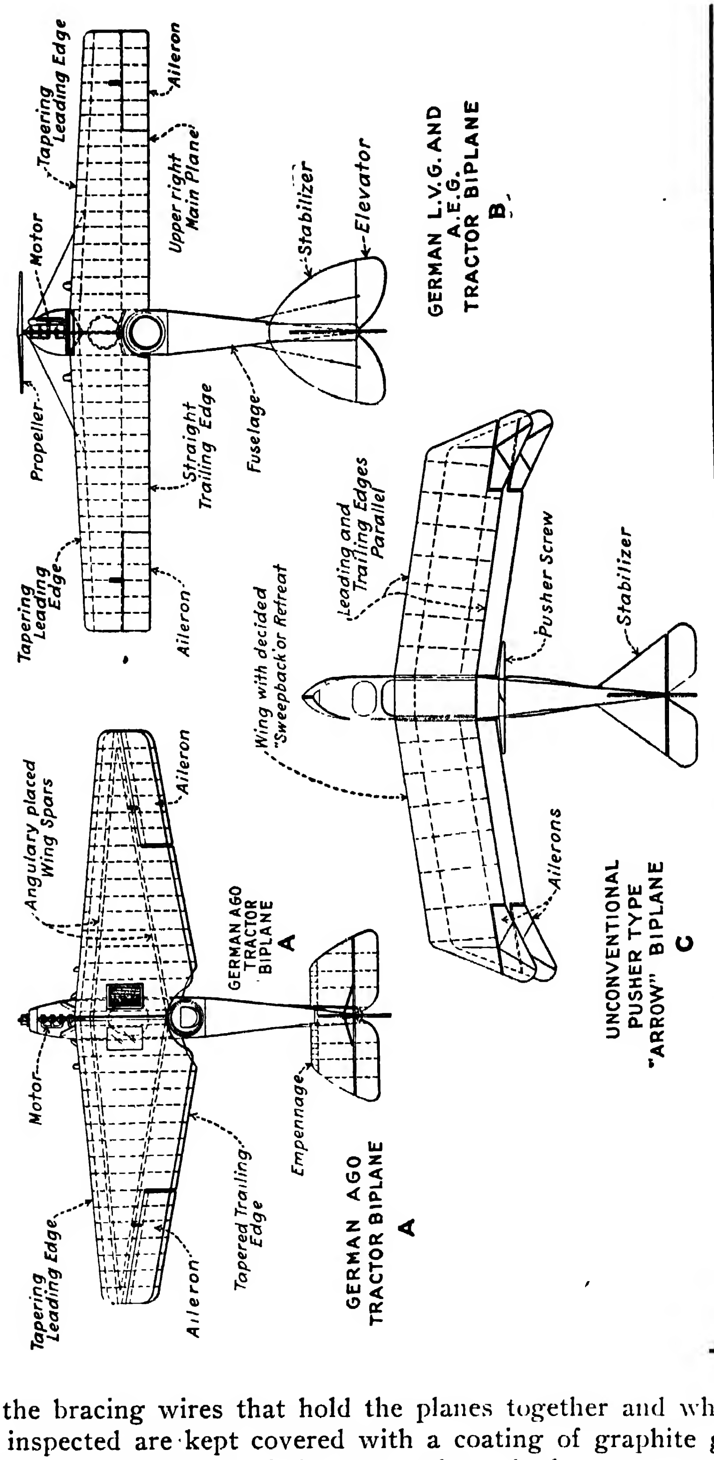


Fig. 71.—A Comparison of Three Early Wartime Types of Rather Curious Designs. Those Shown at A and B are of the Tractor Type, while that Shown at C is of an Unconventional Pusher Type.

while the bracing wires that hold the planes together and which can be easily inspected are kept covered with a coating of graphite grease. In tightening bracing wires it is important that only the proper amount of tension be given, as, if the turnbuckles are tightened too much the interplane

struts are apt to be bowed and their strength greatly reduced. When a plane is put into commercial production in sufficiently large quantities, bracing rods or wires of streamline section having threaded ends to receive the tensioning members are often used instead of the usual round section steel wire cables. The modern tendency is to eliminate as many struts and bracing wires as possible. The biplane designs at Fig. 69 B and C show the use of but one set of interplane struts on each side and where the wings have considerable overhang, the wing spars are made strong enough to carry landing and flying loads without bracing wires as used at A.

Airplane Wing Form.—Mention has been made previously of the influence of varying wing forms if considered from their plan view and a number of simple diagrams have been presented showing typical wing plans. The arrangement of the airplane supporting surfaces in relation to the rest of the airplane structure and the manner in which theoretical forms are modified to meet practical conditions may be clearly ascertained by referring to Figs. 70 and 71. The plan at A, Fig. 70, is a typical training biplane which has both a pronounced forward stagger and an overhang as well, and the upper and lower planes have a decided retreat or "sweep back." The function of this is to give a certain inherent stability under the influence of side gusts as will be explained later. It will be observed that the ailerons or balancing flaps are larger at the tip of the wing and that, when in the normal flying position, the wing has a greater chord at the tip than it has nearer the airplane body. The function of this swelling out of the ailerons is to provide more surface in order to compensate for the lessened lifting influence due to eddy currents which exist around the wing tips.

If one compares the plan at A with the arrangement shown at B, Fig. 70, which outlines a very successful machine, it will be evident that all designers do not avail themselves of the aerodynamical advantages to be obtained by incorporating some of the finer points of design. The biplane shown at B has both upper and lower wings of the same spread and the leading edge of the wing is at right angles to the fuselage. Both upper and lower wings have the same spread and practically the same amount of surface and both are provided with balancing flaps or ailerons whereas the machine shown at A has ailerons only on the upper planes. It is evident that it is much easier to build a machine when planes of the same size are used, and the installation can be considerably stronger when the wings have no "sweep back" or retreat.

If one studies the plan views shown at Fig. 71, some unusual airplane forms may be seen. That at A is the German AGO tractor biplane and has wings of the very peculiar form depicted in which both leading edge and trailing edge taper from the fuselage toward the wing tip. The angularly placed wing spars actually meet at the wing tip and it is claimed for this design that not only are some of the advantages of the retreating wing plan obtained, but that a wing plan form that more nearly meets theoretical conditions than other form is secured. Mention has been previously made of the advantages obtained by having the greatest chord of

the wing near the fuselage and having a decreasing chord toward the wing tip. In the form shown at B the wings have a tapering leading edge so that the effect of a retreat is obtained to a slight extent at that point, but there is a straight trailing edge which is at right angles to the center line of the fuselage which would seem to entirely nullify any supposed advantage gained by the tapering leading edge.

All of the machines shown and thus far discussed have been of the tractor type with the propeller or air screw mounted at the front end of the fuselage. A distinctive and unconventional type, which is shown at C, Fig. 71 has a pusher screw located back of the wings, but at the same time follows the usual construction in which an entirely covered-in streamline body is used instead of the usual open-work or outrigger construction which is necessary to carry the empennage in the usual pusher type. This design, due to Edson Gallaudet called for a rather complex fuselage structure where the propeller was located, this being also an unconventional design in which the blades were fastened to a ball bearing ring member driven by gearing, the ring being of large diameter so it could revolve around the fuselage. While the wings of this machine are set with the decided sweep back or retreat, a pronounced stagger is also provided. The ailerons, or balancing flaps, are placed on both upper and lower wings and are of the form that are enlarged near the tip, instead of the usual simple type, such as shown at B.

A study of the various designs, shown at both Figs. 70 and 71 will show that various designers have different opinions regarding the best plan form for the empennage members. Some of the stabilizers have gracefully rounding sides, while others are approximately triangular in form. There is also some difference in the form of the elevator flaps, but there is not much difference in the area provided for these surfaces relative to those of the main aerofoils. Very little is being done at the present time with unconventional plane forms, because practically all of the development work is being concentrated on the improvement of the power plant and structure to reduce parasitic resistance. Almost any type of airplane will fly if it is given power enough, regardless of the shape or arrangement of the supporting and auxiliary surfaces if standard aerodynamical principles are not departed from too greatly. Of course, the fact that almost any plane will fly is not allowed to interfere with the development of structures that will be efficient and carry maximum loads with minimum power or attain high speeds without excessive engine energy consumption.

Planes With Longitudinal Dihedral.—Practically all airplanes at the present time are provided with stabilizing and control surfaces at the rear of the main supporting members, but some airplanes have been built in which the elevator has been placed at the front, but this is no longer considered good practice. While it was satisfactory with airplanes of early design that had relatively low speeds, the defects of this system were made apparent as soon as the airplane had been developed to a point where greater speeds were obtained. There have been types of airplanes developed that possessed no stabilizing surface as distinct from the main supporting surfaces and in these the arrangement of the main planes was in a pronounced V or the planes were given an exaggerated retreat or sweep back,

which is sometimes called a longitudinal dihedral, which was said to assist in making such a design automatically stable. With this form it is necessary to give a decreasing angle of incidence toward the wing tips and also to change the camber of the wing from the center section to the tips. The function of the wing tips is then such that they act as longitudinal stabilizers.

One of the disadvantages of this construction is that it is a more difficult form to build than the conventional design, which in plan has supporting surfaces in the form of a parallelogram. In order to secure strength the wings must be considerably heavier. Another disadvantage is that the

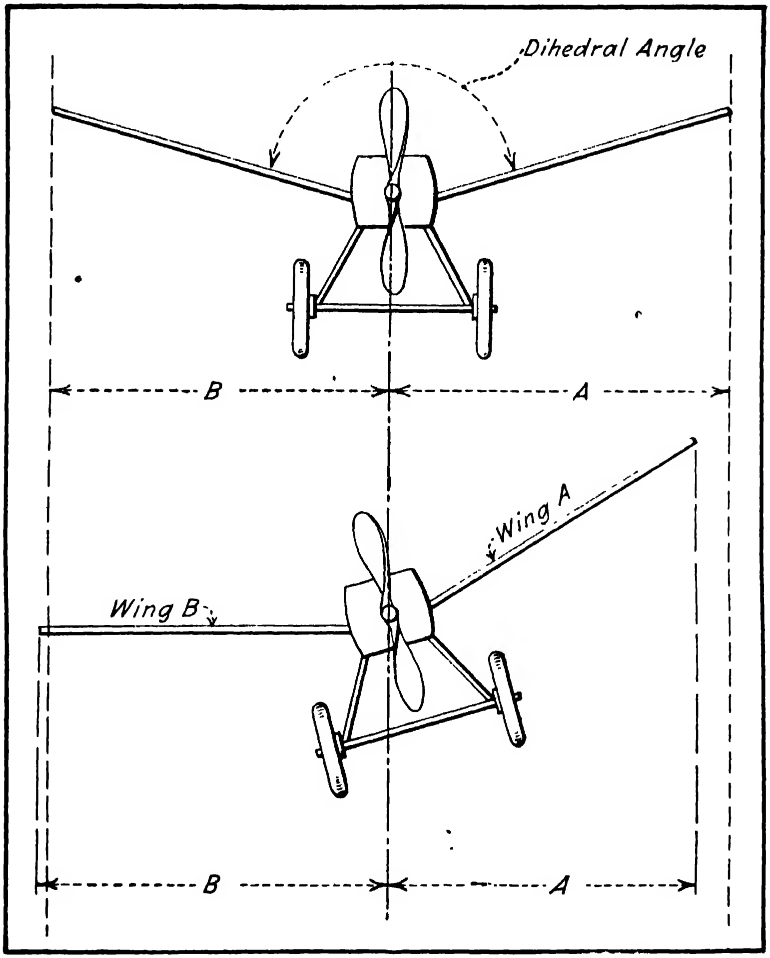


Fig. 72.—A Monoplane Having a Somewhat Exaggerated Lateral Dihedral.

aspect ratio is not as large as would be the case if the leading edges of the wings are placed at right angles to the center line of the fuselage. Any airplane having a pronounced sweep back has a lower aspect ratio than the usual construction would have with the same length of leading edge, and as the efficiency of the lift decreases with a lessened aspect ratio, the

V wing arrangement would produce less lift for a given weight of supporting surface than would be the case if the wings were arranged approximately in the form of a parallelogram as shown at Fig. 70 B, instead of having a pronounced retreat as outlined at Fig. 71 C. It is evident that the decreasing camber of the wings can be obtained only by using ribs of different forms at various portions of the wing and that this results in added expense. The longitudinal dihedral is not used to any extent at the present time because its theoretical advantages do not balance the practical and structural disadvantages inherent with this design.

Influence of Lateral Dihedral.—While the longitudinal dihedral is not used to any great extent the lateral dihedral has been applied in many designs because it aids in securing lateral stability. A dihedral angle is obtained by inclining the supporting surfaces up from the center of the fuselage so that the wing tips are higher than the other portions of the wing. A monoplane having a pronounced and somewhat exaggerated lateral dihedral is shown at the top of Fig. 72, under normal flying conditions. Just as is the case with the longitudinal dihedral, the effective span or wing spread is not represented by the actual length of the leading edge, but by projected distances A and B, which are termed "horizontal equivalents." It will be observed that under normal flying conditions, the distance A is equal to the distance B. This, of course, results in the lift of one wing being equal to that of the other. If, however, a gust of wind causes one side of the machine to tip, as is shown in the lower part of Fig. 72, it will be apparent that the horizontal equivalent of the lowest wing which is shown in a horizontal position and which is represented by the letter B becomes greater than that of the other wing as represented by the distance A. The wing B will have a greater lift than wing A and therefore will tend to rise while wing A will depress until the normal flying position is reached.

While the automatic stabilizing effect is not directly proportional to the difference between the horizontal equivalents A and B, and while other factors, such as amount of keel surface and disposition of the center of gravity, affect the automatic recovery, at the same time the lateral dihedral offers some advantages. Experiments in the wind tunnel have shown that moderate dihedral angles up to 14 degrees included angle, or 7 degrees angle at each wing, do not reduce the aerodynamical efficiency appreciably and at the same time some degree of automatic lateral stability is secured. A well-known training machine of the tractor biplane type has a lateral dihedral of 4 degrees on each wing or a total included angle of 8 degrees between the two. This means that instead of the wings being placed 180 degrees from tip to tip as would be the case if they were absolutely horizontal, the space between wing tips would be 180 plus 8 degrees if measured from underneath and 180 minus 8 degrees if measured from the top.

Biplane and Monoplane Wing Bracing.—If considered purely from an aerodynamic point of view the monoplane has decided advantages and is a more efficient form than the biplane, but as has been outlined in a previous discussion of this subject the reduced efficiency of the biplane is more than compensated for by the increased strength of the biplane structure in the opinion

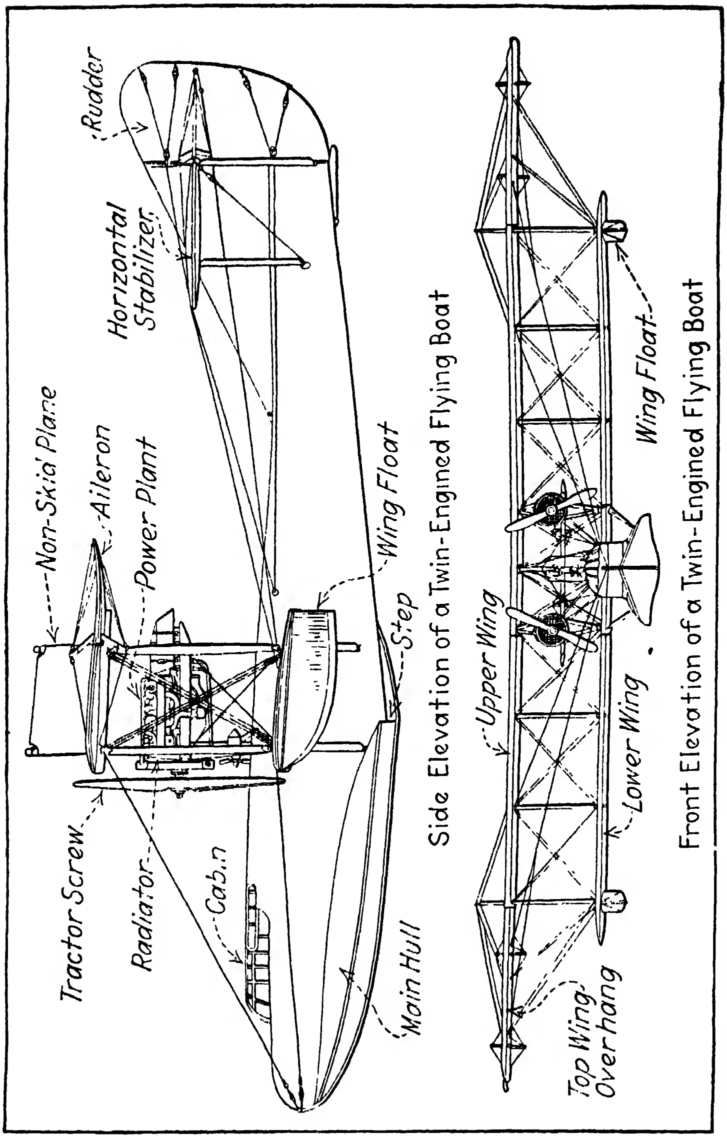


Fig. 72A.—Side and Front Elevation of Twin Engine Flying Boat Showing Principal Parts. Note Slight Lateral Dihedral and Wing Bracing Employed.

of its proponents. The advantages of the biplane are not so firmly established at the present time as they were during the War and many aeronautical engineers are turning to the monoplane. The first biplane form was poorly designed and had so much exposed wiring and struts of such clumsy form that it offered considerably more resistance than the smaller and lighter monoplane did. The latter offered less resistance because it had no struts and was enabled to operate with higher efficiency because there was no interference between upper and lower surfaces as is the case with the biplane. Improved design and careful bracing have made it possible to build biplanes that are very fast and that are able to lift heavier loads than a monoplane of the same effective area built of materials per-

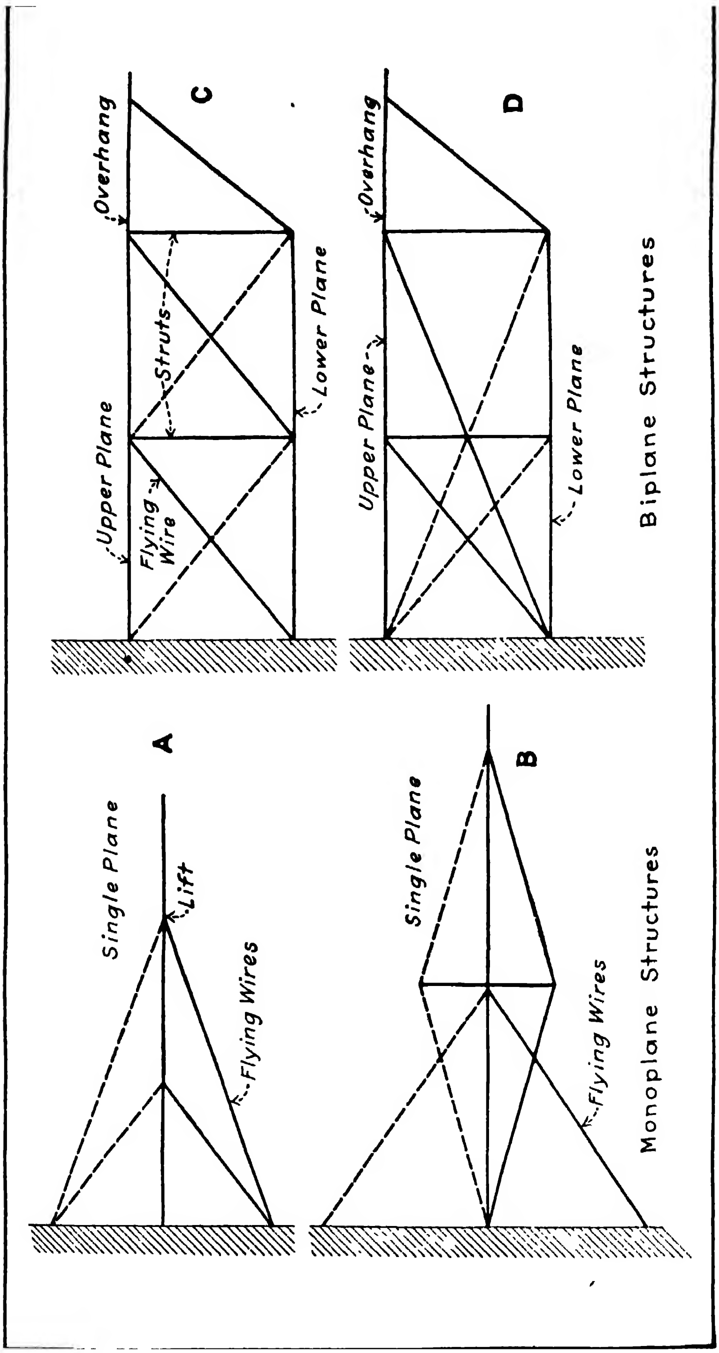


Fig. 73.—Diagrams Showing Four Typical Wing Structures, Illustrating the Methods Employed in Bracing Each Type by External Bracing Wires.

mitting only low wing loadings, such as wood and fabric. This is changed by the use of metal construction, however.

As the size of machines increases the biplane structure offers advantages. We have seen that the construction of a wing consisted of two wing spars which were joined together by transverse ribs. The connec-

tion of the wings to the fuselage of the airplane is at the inner end of the wing spars so that we can consider one side of any airplane as a cantilever beam. The two methods of bracing the monoplane by wires are shown at Fig. 73 A and B. The flying wires, which are those that assist the wing in carrying the load by transmitting some of it to the fuselage, are indicated by solid black lines while the landing wires are indicated by dotted

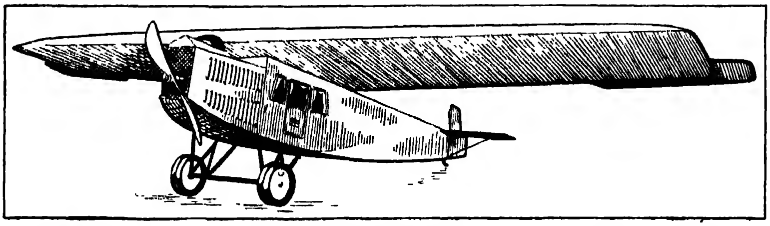


Fig. 74.—The Fokker F III Cabin Monoplane which has been Successfully Used on European Airlines has Internally Braced Cantilever Aerofoil of Wood Spars and Ribs Surfaced with Veneer.

or broken lines. The scheme shown at A is the most common one as the construction outlined at B has been practically abandoned. The biplane structures which are shown at Fig. 73 C and D may practically be considered true girders of the box or trellis type. As is true in the preceding example, the flying wires are indicated with solid black lines, while the landing wires are shown by broken lines. By these comparisons it can

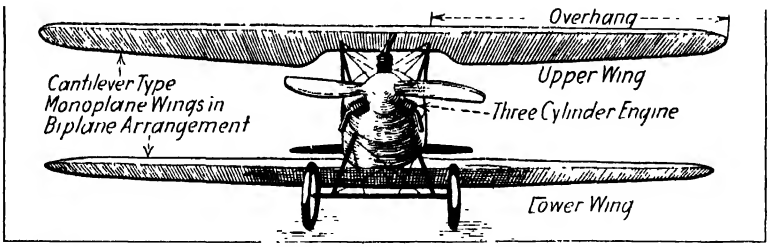


Fig. 75.—The Arrow Sport Biplane has Cantilever Wings of Tapered Section and has no Interplane Struts or Bracing Wires to Offer Resistance to Flight.

be seen that the biplane system may be so worked out as to offer a stronger and more rigid construction than is possible with a monoplane system, weights and supporting surfaces being equal, if the bracing effect is limited to external wires only. When thick section wings are used on monoplanes, they may be so well braced internally that no external wires are necessary and ample strength obtained by the depth of the spars at the fuselage. A very efficient design of monoplane is shown at Fig. 74, which shows the form of a thick section wing and how it tapers from its major dimension at the root or point just above the fuselage to the tip, the internal spars forming a true cantilever truss construction. The wing shown is of wood construction, the surface being of plywood. An unusual design of biplane is shown at Fig. 75. In this, there are no interplane struts or bracing wires except at the center section. The wings are of the cantilever monoplane

type and parasitic resistance is less than when struts are employed between the aerofoils. This is a compromise design to secure adequate lifting area with small span and at the same time secure some of the aerodynamical advantages of the monoplane. Unfortunately, this arrangement does not eliminate the aerodynamical disadvantage of lessened lift due to superposed surfaces which the writer has previously discussed.

Side Bracing of Airplane Wings.—The side bracing of airplane wings can be done in many different ways and there are many possibilities in the design of the interplane struts by which the usual wire bracings, which

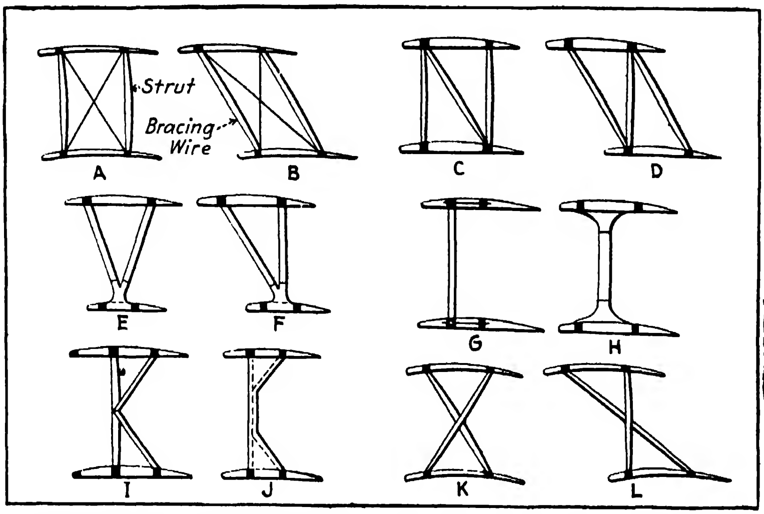


Fig. 76.—Showing Several Methods of Bracing Biplane Wing Structures, and Illustrating the Function of the Struts in Each Case.

are called "incidence" wires, may be dispensed with entirely. The most common systems are shown at A and B, Fig. 76, and are based on the same principle, the difference being that the form at A is adapted for a biplane having its leading edges parallel while that at B has a positive or forward stagger. Naturally, the struts must be inclined in the design shown at B. The construction shown at C is known as the N-type bracing, and at D its application to a staggered biplane construction is shown. It is stated that the use of three struts offers less resistance than two struts and two wires do. In fact, it has been proved that the resistance produced by the wires in the design shown at A or B will be reduced about 50 per cent if the construction shown at C or D is adopted.

The bracing system depicted at F shows the V-type bracing which has been adopted on some of the Nieuport fast scout biplanes. The converging struts are assembled in a special streamline socket fitted between the spars of the lower wing, and while it is also adaptable to the usual biplane form as shown at E, its field of greatest utility lies in the unequal chord biplane having a pronounced forward stagger. In the early days, Breguet designed a single lift truss biplane of the form shown at Fig. 76 G. As his main object was to vary the angle of incidence of the wings automatically, these were hinged to tubular spars and a spring bracing member having

some degree of flexibility extended from the tubular spar to the rear spar of the wing. This construction brought the spars considerably nearer together than they would be in the conventional design wing and the entire structure was not as strong as the other designs employing double lift truss construction.

The I-type side bracing that has been used in an effort to reduce parasitic resistance is shown at Fig. 76 H. In this construction special sockets are used which have long bases reaching from the front to the rear spar, and these project from the wing surface an appreciable distance in order that the single strut will project into the socket far enough to secure the necessary strength and rigidity. The Martin K-type side bracing, which is shown at Fig. 76 I, has many advantages, and while it offers but little more resistance than the I-type shown at H, it eliminates the bending moments due to the cantilever socket construction. A modified system of the K-type side bracing is shown at Fig. 76 J. This is a single lift truss designed by Curtiss and built up of two steel tubes, one of them being bent in such a form that it can be readily fastened to the front strut for an appreciable length. When either of the K-type side bracings are used it is possible to streamline them so effectively as to secure a marked reduction in resistance. The X-type side bracing, which is shown at Fig. 76 K and L, is not used to any extent at the present time, though it would seem to offer some advantages over the conventional construction shown at A

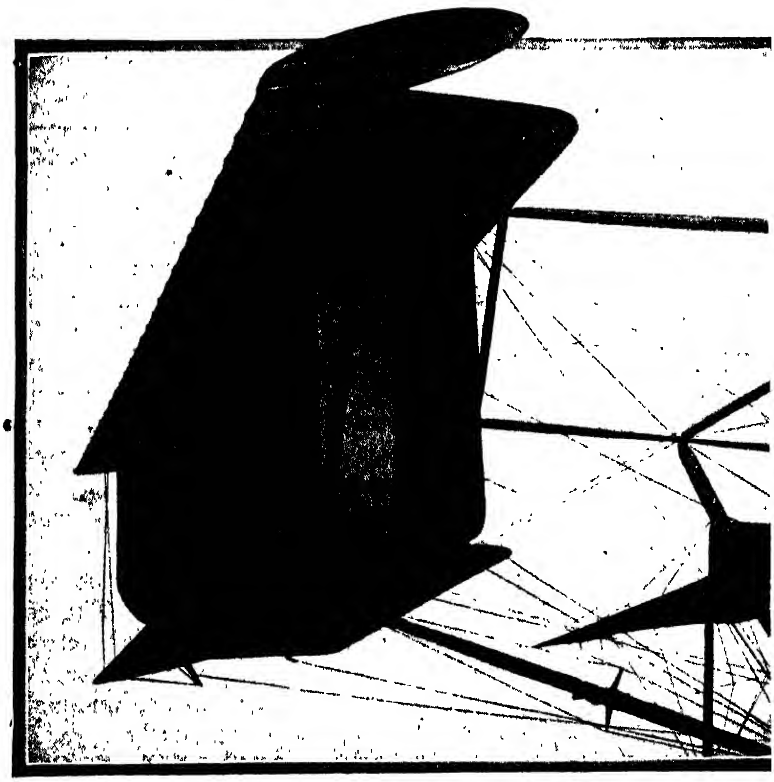


Fig. 76A.—Empennage of the NC-4 Flying Boat Showing how Bracing Wires are Employed in Strengthening the Assembly.

and B, because it eliminates the bracing wires, though perhaps more resistance would be caused due to the struts crossing each other, which would place them in slightly off-set relation to each other, whereas in other two strut arrangements one is behind the other.

Airplane Bracing Wires.—Three kinds of steel wire are used for bracing, one being a hard wire of round section while another is a flexible cable or steel rope. There is a third type known as R.A.F. wire, which is a rod of streamline section provided with tensioning and attaching fittings at each end. This form can only be used where it was designed to fit as it can be shortened

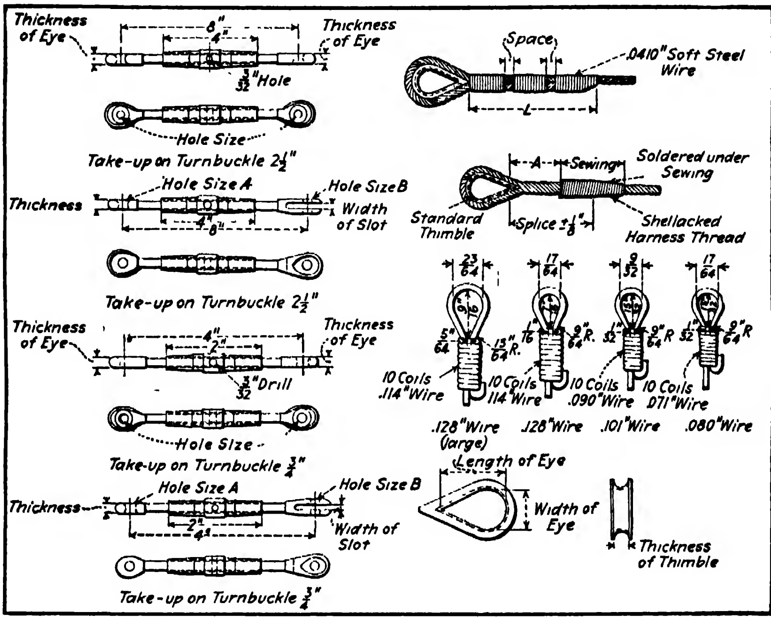


Fig. 77.—Details of Standardized Thimbles and Turnbuckles.

or lengthened only within narrow limits. The stay wire loops and the method of forming eyes in both flexible cables and hard wire by the use of thimbles, around which the flexible cable is bent and afterwards securely held together by a serving of soft steel or copper wire well soldered, is shown at Fig. 77. The hard wire loops are made by using oval coils of wire as sleeves and bending up one end of the wire as shown, afterwards soldering the whole to insure that the parts will stay in the proper relation. In order to insure that the bracing and stay wires will be properly tightened, turnbuckles are interposed in each wire. These may easily be tightened by inserting a pin in the turnbuckle body, and, after the cables have been tightened to the proper degree, the turnbuckles are "safety wired" by passing copper or soft iron wire through the turnbuckle body and then wrapping it through and around the eyes in such a way that the turnbuckle body cannot become loosened without the safety wire being cut and removed. This renders it impossible for a cable to become loose due to vibration while the machine is in flight. The appended data regarding the various cables and hard wire, as well as the turnbuckles generally

used in airplane wire bracing work, has been suggested by the Aeronautic Division of S.A.E. This gives sizes and strength of wires of various kinds.

Non-Corroding Soldering Flux.—Various types of soldering flux and paste have been used in different aircraft contractors' plants. The largest use for these has been in the soldering of splice terminals on wire cables. It has been found that whenever certain of these soldering compounds are used, rapid corrosion of the cable occurs, as the compounds contain acid ingredients which work down into the strands. Examination of a great many samples of different types of soldering compound show in practically every instance a very large proportion, from 20 to 80 per cent, of zinc chloride, sometimes admixed with ammonium chloride or mineral oil. The purpose of the zinc chloride is to have present a material that would hydrolize to an acid reaction which would cleanse the surface of the metal by dissolving the oxides and make a good soldering surface.

It has been found that the use of such compounds can be done away with entirely, and one cause of corrosion eliminated by the use of a soldering flux free from mineral acid. The flux consists of rosin with an organic acid compound such as stearic acid, these two ingredients being melted together in equal quantities by weight. This material has practically no solvent effect upon metal but cleanses the surface sufficiently from the oxide to present a good soldering joint. Some slight difficulties were at first had with contractors who endeavored to make up their own soldering compound to the above formula, reports being to the effect that they did not get sufficient cutting effect with the compound. These instances, however, showed that they had purchased stearine in place of stearic acid. Stearine, as is well known, is a glycerine ester of stearic acid and has no acid value, being neutral. Stearic acid, on the other hand, has a high acid value of 200, and when used with rosin forms a soldering flux that gives very satisfactory results.

Hard Wire Loop.—This consists of an oval coil of wire through which the hard wire is slipped, bent in the form of a loop, again inserted, and the end bent over against the coil. The whole is then soldered. This is identical with the present British standard.

Flexible Cable Ends.—The sketch shows the cable end wrapped around a "standard thimble." The length of splice from pointed end of opening in thimble was represented by "splice plus or minus 1/8 inch." The end of the splice is wrapped with a serving of shellacked harness thread. Dimension A represents the distance from end of opening in thimble to end of serving.

Diameter of Cable	Length of Splice	Number of Tucks	Length of Serving	Full Strength of Cable
3/32 7 x 14..........	1¼		1	½ 800
1/8 7 x 19..........	1½	3 over	1	½ 2000
5/32 7 x 19..........	1¾	core buried	1¼	½ 2800
3/16 7 x 19..........	1⅞	4 under	1¼	¾ 4200
7/32 7 x 19..........	2⅝		1¼	¾ 5600

Galvanized Non-Flexible Ends.—The cable end is wrapped about a thimble, with a total length of splice indicated by L; 0.041 inch soft steel wire is to be used for wrapping, and the sketch indicates two spaces left between convolutions of the wrapping wire, width of the spaces being indicated in the table. The accompanying table gives the sizes and strengths:

Diameter of Cable	L	Space	Wind	Full Strength of Cable
1/16 1 x 19.............	1½	1/8	1	500
3/32 1 x 19.............	2	1/8	1¼	1100
1/8 1 x 19.............	2½	1/8	1½	2100
5/32 1 x 19.............	2¾	1/8	2	3200
3/16 1 x 19.............	3	3/16	2¼	4600
7/32 1 x 19.............	3½	3/16	2¼	6100
1/4 1 x 19.............	4	1/4	2½	8000

U. S. Army Bracing Wire Practice.—The stays and brace wires now in general use in army airplane construction may be divided into five classes: solid streamline wire, non-flexible cable, flexible cable, round swaged wire, and solid aviator or piano wire. The material used for interplane bracing and also for the landing gear and empennage stays may be either streamline wire, such as that shown at 6 in Plate 17, or non-flexible cable consisting of a number of strands or individual wires, as illustrated at 1, 2 and 3 in the same plate. For controls, and particularly those which pass over comparatively small pulleys, flexible cable usually is employed. This is quite similar in appearance to the non-flexible, except that its main strands, instead of being single wires, consist of a number of much smaller wires. Internal braces or stays in the fuselage and wings are made of either round swaged wire or solid aviator wire, some designers and builders favoring one type and some the other.

One of the most serious difficulties encountered in using any style of stay or brace is the proper looping and splicing of the ends so that the terminal attachments will be as strong as the wire itself. Various types of terminals are used in securing the ends of the brace wires to the parts of the fuselage, wings, etc. For instance, streamline and swaged wires are provided with right and left hand threads at the ends, which screw into clevises or internally threaded sleeves having yokes at the outer ends that are secured to plates or eyes fastened to the fuselage or other part to be braced. Adjustment is secured by turning the wire itself, inasmuch as the clevis usually is attached to its mounting by a cross pin which prevents it from rotating. When the proper adjustment has been reached, locknuts on the threaded ends of the wires are screwed down tight against the clevises. The type of terminal used with streamline wire is shown at 6 in Plate 17, and that for swaged rod at 9.

For either flexible or non-flexible cables, terminals usually are made by bending around thimbles and then securing the free ends to the main part of the strand either by plain soldering or by splicing, as shown in Plate 17. The splicing operation consists of separating the strands at the end of the

cable and also those of the body just below the point of the thimble, and interweaving the two sets of strands, so that when pulled tight, they will form a compact joint as strong as the cable itself. The splices may be soldered, although this is not always considered necessary with some types. They also are usually served, or bound with fine wire or similar material wound over the full length of the splice. A cable with thimbles spliced into it at both ends is adjusted for length by means of a turnbuckle between one end and its attachment.

Solid aviator wire is secured at each end by forming a loop of the wire itself, slipping a flattened sleeve or ferrule over the main wire and the loop end, and then bending back the end alongside of the ferrule. The various steps in forming such a terminal are shown in order. Adjustment for length in this case also is obtained by using a turnbuckle at one end.

Streamline Wire.—The chief advantage of streamline wire is that it reduces the parasite resistance. For this reason it is much used on war planes, especially by the British and to some extent by the United States. It is only required, of course, for exposed places, such as interplane, landing gear and empennage braces. It is estimated that on a machine of the DeHaviland-4 type, travelling at a velocity of 150 m.p.h., and increase in speed of 7 m.p.h. could be realized by using streamline wire throughout, instead of round cable, for all exposed stays. The terminals used with streamline wire are usually universal clevises similar to that shown at 6 in Plate 17. As regards strength, this material is approximately equal to round non-flexible cable of the same size and weight.

Non-Flexible Cable.—Until quite recently this material was used to a great extent for interplane stays, drift wires, landing gear braces, etc. Lately, however, streamline wire has taken the lead. Non-flexible cable is considered better than the flexible variety for most uses, being from 5 to 14 per cent stronger. It is also less subject to deterioration, as its component wires are fewer in number and of greater individual strength than those of flexible cable. The latter also stretches considerably when in use, whereas non-flexible cable has no appreciable elongation. Hence planes on which non-flexible stays are used will retain their alignment much better than those in which the external braces are of the flexible material. The latter is easier to splice than the non-flexible cable, however, and perhaps on this account is more frequently used by foreign designers, especially by the British. Non-flexible cable usually is made of nineteen individual strands.

Flexible Cable.—Control wires, on account of having to pass over pulleys, usually are made of flexible cable which consists of seven strands of nineteen fine wires each, or 7 by 19 cable, as it is called. Although it may stretch slightly, as previously brought out, this point is not so important in the case of the control wires, as they are never adjusted so tightly as the stay wires or other braces required to maintain the alignment of the plane. The end attachment used with flexible wire consists of a thimble around which the end of the cable is looped and afterwards spliced to the body section. In this case also adjustment is provided by means of a turnbuckle at one end of the wire. Inasmuch as the general methods of splicing are the same for either the flexible or non-flexible cables, this subject will be treated as a separate division.

Thimbles.—These thimbles are shown by appropriate drawings. The sizes are indicated roughly by the following table:

Size of Rope	Thickness of Thimble	Width of Eye	Length of Eye
$^1/_{16}$–$^3/_{32}$	0.075	0.35	0.70
$^1/_8$	0.12	0.35	0.70
$^5/_{32}$	0.17	0.40	0.80
$^3/_{16}$	0.21	0.50	1.00
$^7/_{32}$	0.24	0.60	1.20
$^1/_4$	0.27	0.70	1.40
$^9/_{32}$	0.30	0.80	1.60
$^5/_{16}$	0.33	0.90	1.80
$^3/_8$	0.39	1.00	2.00

Turnbuckles.—Detail dimensions of both short and long types are given in Fig. 77. The following main dimensions are recomemnded for immediate adoption:

(With either two eye ends or one eye and one yoke end.)

	Short	Long
Length of barrel	2	4
Length between eyes:		
With threads flush with ends of barrel	4	8
With maximum extended	$4^3/_{16}$	$8^3/_{16}$
With minimum extended	$3^1/_4$	$5^1/_2$

Strength (Lbs.) S. A. E. Numbers	Short	Long
1	500	500
2	1000	1,000
3	1500	1,500
4	2000	2,000
5	2500	2,500
6	3000	3,000
7	3500	3,500
8	....	4,000
9	....	4,500
10	....	5,000
11	....	6,000
12	....	7,000
13	....	8,000
14	....	9,000
15	....	10,000

Round Swaged Wire.—This type of wire is used quite generally for the internal bracing of wings and fuselages. Each brace or tie rod must be cut and finished to exactly the proper length, however, so that the material is not altogether suitable for miscellaneous or experimental uses, although it is quite good for quantity production where every piece is made

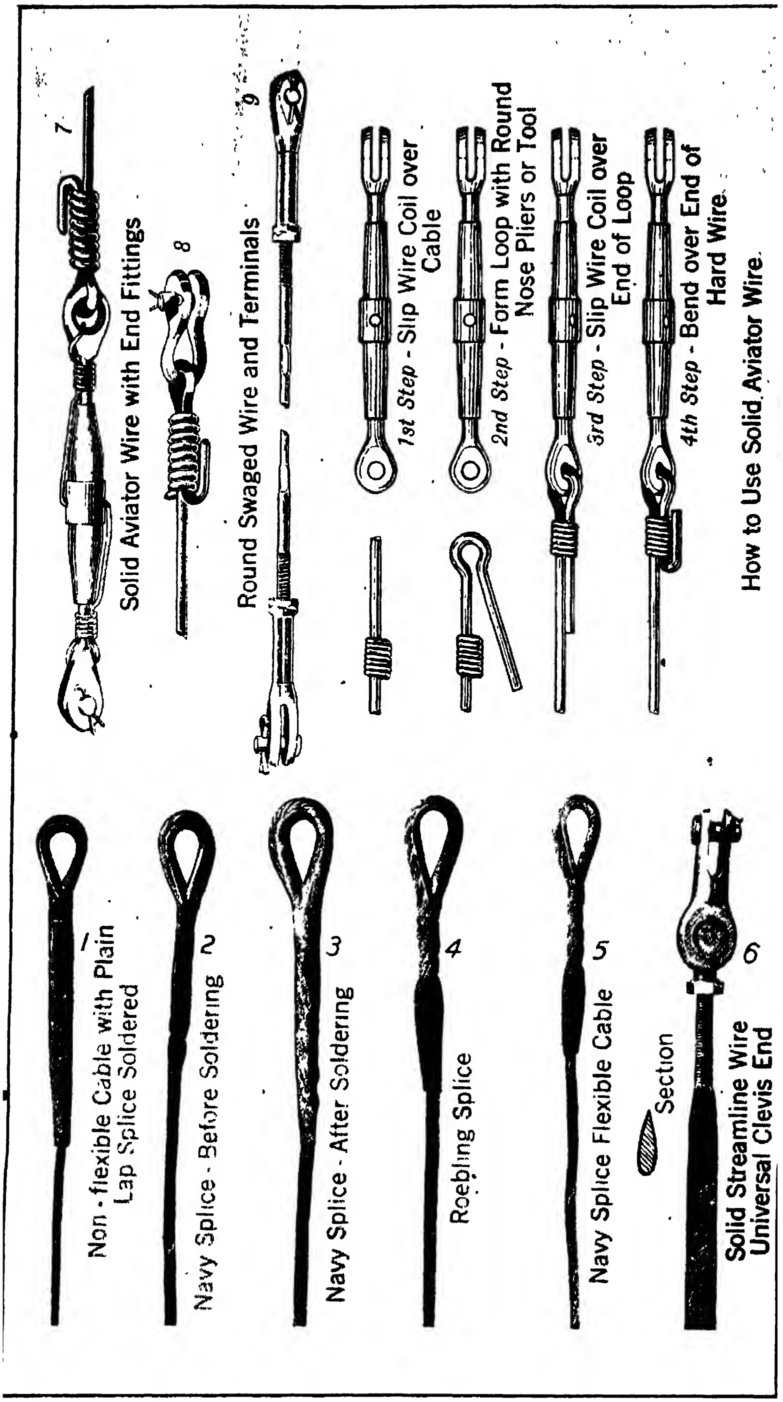


Plate 17.—Various Types of Bracing Wires and Cables, Showing Splices and Connections Used in U. S. Army Practice.

to specifications. Both ends of a round swaged tie rod are threaded, one with a right-hand thread and the other left, and screwed into clevis attachments. Each end of the rod is squared just inside the threaded portion so

that a small wrench can be used to turn it for tightening or adjustment. A small locknut is screwed on to each threaded end before it is inserted in the clevis and after the proper adjustment has been obtained the locknuts are tightened.

Experiments have shown that there is little or no difference in the strength of a stay with either type of splice, as the cable will usually break either in the center of its length or else just at the end of the splice. Without question the box type is the safer of the two, however, where there is any danger of the cable being twisted or exposed to heat intense enough to melt the solder in the splice; as lap splices depend upon the solder for their strength more than the wire serving.

Soldering and Serving.—While both box and roll splices are made stronger by soldering, this is not so necessary with the former as with the latter. Soldering is a requisite part of the plain lap splice, however, as previously explained. It is considered important that all splices in the control wires near the gasoline tank, or in other places where they may be exposed to intense heat, be of the box type. In case of heat sufficient to melt out the solder, this form of splice would still continue to hold, where the roll type might not.

Overheating and corrosion must be guarded against in all soldering operations on cables and splices. It is an easy matter to overheat and soften the wire, and as the softening takes place at a point where the wire is more or less weakened on account of being pulled loose in making the splice, it is all the more serious. Corrosion generally is due to the action of poor or unsuitable fluxes. The soldering of plain lap splices already has been described in connection with the making of the splice, soldering being an integral part of the operation. Cleanliness is of prime importance in all soldering operations. The soldering copper must be free of all foreign substances and well tinned, as dirt would almost certainly spoil the work. The parts to be soldered also must be clean. The soldering copper can be tinned by heating it to about 600 degrees fahrenheit and then dipping the point quickly into ammonium chloride (NH_4Cl) and granular tin or small pieces of solder. Another way is to prepare a quantity of soldering flux and a small piece of solder, placing them in a depression in a piece of sheet tin; then after filing the copper until bright, heat it to 600 degrees fahrenheit and move it around in the solder and flux until it becomes coated with molten solder, when it will be ready to use.

In all soldering operations in connection with airplane cables it is very important to use a non-oxidizing flux. No flux containing any oxidizing acid should ever be employed as a cleaning agent preparatory to soldering cable splices, especially on cables where its removal would be difficult, or where it might get in between the strands and attack the metal. Soldering fluxes specified at the present time, and which are satisfactory on tinned wire, are stearic acid, stearic acid and rosin, or rosin dissolved in a suitable solvent. Where an acid flux has been used, its corrosive effect often may be neutralized by the application of an alkaline solution, such as soda water. However, with stranded cable, where the acid may be driven into the interstices between the fine wires by the application of heat, it is questionable whether any system of washing will eliminate or neutralize the

acid. Corrosion may therefore occur in the interior wires, while the exterior appears to be in good condition.

Tests of Spliced Cables.—A considerable number of tests of spliced cables have been made from time to time, in order to determine the comparative strength of the different types of splices and of the cables themselves. It was noted that failures occurred in the splices in only a small proportion of the tests, and then usually in the lap splices. Where these were soldered, however, such failures as occurred in the splice took place at loads greatly in excess of the rated strength of the cable itself. For example a soldered lap splice 3/16 inch cable broke in the splice when a load of 4,730 pounds was applied, whereas the rated load of the cable was 4,600 pounds.

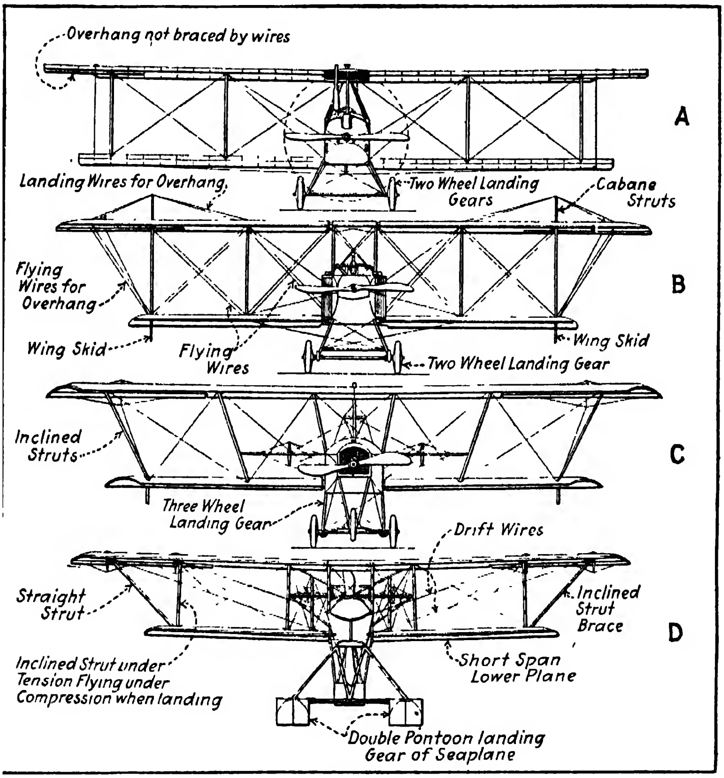


Fig. 78.—Showing Arrangement of Bracing Wires on a Number of Airplanes of Different Design.

Typical Wire Bracing Arrangements.—The arrangement of bracing wires on a number of biplanes of different design is given at Fig. 78, so that the student may determine the various kinds of bracing ordinarily used. The simplest construction is shown at A. In this, the overhang of the top plane is not braced by any wires and all of the strain produced by the lift while flying or the reverse load when landing must be taken entirely by the

wing spars. In the tractor biplane, shown at B, the overhang is braced by flying wires which extend from the bottom of the outside strut to the wing spars. The overhang is also braced by landing wires which are stretched over cabane struts on the top of the upper plane. In the tractor biplane, shown at C, the struts are inclined instead of being straight up and down as in the form shown at A and B. The difference in landing gear construction and bracing can also be easily determined from these illustrations. Two-wheel landing gears of simple form are used on the planes shown at A and B, while a three-wheel landing gear of somewhat stronger construction that also offers more resistance is shown at C. The seaplane shown at D, Fig. 78, has the overhang braced by an inclined strut which is under tension while flying and under compression when landing. The arrangement of the drift wires which extend from the front of the fuselage to the wings is also apparent. It will be observed that the wings of the seaplane are set at a slight dihedral angle and that the pontoon landing gear must offer considerably more resistance than the simpler wheeled landing gears of the land machines, though in modern machines the under surface of the pontoons or floats are formed to secure some lift while in flight and careful streamlining of the section reduces parasitic resistance to a minimum.

Airplane Dimensions and Characteristics

angle of stabilizer setting—The acute angle between the line of thrust of an airplane and the chord of the stabilizer.

angle of wing setting—The acute angle between the plane of wing chord and the line of thrust. It may differ for each wing.

decalage—The acute angle between the wing chords of a biplane or multiplane.

gap—The distance between the planes of the chords of any two adjacent wings, measured along a line perpendicular to the chord of the upper wing at any designated point of its leading edge. Its symbol is G. (Fig. 53.)

landing angle—The acute angle between the line of thrust of an airplane and the horizontal when the airplane is resting on level ground in its natural position. Also called "ground angle."

longitudinal dihedral angle—The difference in angle of wing setting and of stabilizer setting. This angle is positive when the angle of stabilizer setting referred to the trust line, is less than the angle of wing setting.

mean chord of a combination of wings—The ratio

$$\frac{c_1 S_1 + c_2 S_2 + c_3 S_3 + \ldots}{S_1 + S_2 + S_3 + \ldots\ldots}$$

where c_1, c_2, c_3, etc., are the mean chords of various wings, and S_1, S_2, S_3, etc., are their areas.

mean chord of a wing—The quotient obtained by dividing the wing area by the extreme dimension of the wing projection at right angles to the chord.

over-all length—The distance from the extreme front to the extreme rear of an aircraft, including the propeller and the tail unit.

overhang—Used in two senses. (1) One-half of the difference in span of any two main supporting surfaces of an airplane. The overhang is positive when the upper of the two main supporting surfaces has the larger span. (2) The distance from the outer strut attachment to the tip of the wings. (Fig. 67.)

span—The maximum distance measured parallel to the lateral axis from tip to tip of an airplane inclusive of ailerons.

stagger—The amount of advance of the leading edge of an upper wing of a biplane, triplane, or multiplane over that of a lower, expressed either as a percentage of gap or in degrees of the angle whose tangent is the percentage just referred to. It is considered positive when the upper wing is forward and is measured from the leading edge of the upper wing along its chord to the point of intersection of this chord with a line drawn perpendicular to the chord of the upper wing at the leading edge of the lower wing, all lines being drawn in a plane parallel to the plane of symmetry. (Figs. 53 and 54.)

sweep back—The acute angle between the lateral axis of an airplane and the projection of the axis of the wing on the plane which includes the lateral and longitudinal axes. (Fig. 70.) (The axis of a wing is a line through the centroids of the sections of the wing.)

washin—Permanent warping of the wing which results in an increase in the angle of attack near the tip.

washout—Permanent warping of a wing which results in a decrease in the angle of attack near the tip.

wing-dihedral or dihedral angle—The acute angle between the transverse reference line in the wing surface and the lateral axis of the airplane projected on a plane perpendicular to the longitudinal axis. The dihedral angle is positive when the upper obtuse angle for the two wings is less than 180 degrees. (Fig. 72.)

wing loading—The gross weight of an airplane, fully loaded, divided by the area of the supporting surface. The area used in computing the wing loading should include ailerons but not the stabilizer or elevators.

QUESTIONS FOR REVIEW

1. What is the effect of "gap" variation in biplanes?
2. What is "stagger" and how does it influence biplane wing lifting power?
3. What is the most efficient aerofoil plan form and why?
4. What are the main elements of a wood and fabric airplane wing?
5. Why is "dope" used for covering fabric wings and how is it used?
6. How is fabric attached to wing structure?
7. Describe advantages and construction of metal airplane wings.
8. What are the principal features of the Rohrbach metal wing construction?
9. What loads must be resisted by airplane wing brace wires? How does monoplane and biplane bracing differ?
10. Describe "longitudinal dihedral" and tell how it differs from "lateral dihedral." What is the influence of "dihedral"?

CHAPTER VI

AIRPLANE FUSELAGE AND LANDING GEAR CONSTRUCTION

Early Wright Starting System—Catapult Launching Gear—Design of Fuselage Framework—Airplane Design Considerations—Reduction of Parasitic Resistance —Airplane Fuselage Forms—Complete Enclosure Important—Wood and Wire Truss Construction—Composite Fuselage Construction—Plywood Fuselage Details —Table IX, Strengths of Various Species of 3 Ply Panels—Table X, Tensile Strength of Plywood and Veneer—Table XI, Thickness Factors for Veneer— Metal Fuselages—Duralumin—Properties of Duralumin—Preventing Corrosion of Metal—Properties of Steel for Fuselage Construction—How Co-incidence of Centers is Obtained—Open vs. Closed Pilot's Cockpits—Landing Gear Forms—Split Axle Landing Gears—Wheel Tread Depends on Spread—Brakes for Airplane Wheels—Balsa Wood Fairing—Woods for Airplane Parts—Metals Used in Airplanes—Table XII, Strengths of Various Materials—Table XIII, Transverse Strengths of Wooden Bars—Mass of Material to Construct an Airplane.

When airplanes were first designed the type of construction followed was to use the wing structure as a main framework which carried the aviator, the power plant and the propulsive screws while control and stabilizing surfaces were carried by outriggers and tail booms and in a number of the early biplane designs the controlling surfaces were placed at both front and rear of the wing structure. In the construction that was first followed in the Bleriot monoplane, shown at Fig. 79 C the power plant was carried at the front of the machine and was mounted in a framework or body which served to carry most of the weight, inasmuch as the tanks for fuel and the seat for the pilot were included in the fuselage. With the tractor monoplane type of construction the control surfaces were carried at the back end of the machine and no control members were placed at the front end. The advantages of this construction were so marked that the older form was discontinued and practically all machines of the single engine type whether of the single plane or multiplane type, were designed on the early monoplane principle of having the wing sections attached to a fuselage which carried most of the weight and the control surfaces instead of the type that offered the most resistance in which practically all of the weight was carried directly by the wing structure.

Early Wright Starting System.—Two early biplanes are shown at Fig. 79. That at the top is the historic Wright creation with which the possibilities of mechanical flight were first demonstrated to an unbelieving scientific world. The type shown below it is a Curtiss creation that did some wonderful work for the early days and which proved to be not only a very reliable type, but one in which the qualities of safety were best developed. It will be observed that there was considerable difference in the design of these two pioneer forms. The Wright machine had its power plant carried on the lower plane, and at one side of the seat occupied by the pilot, which was also on the lower supporting surface. The drive was by chains to two large diameter, relatively slow speed pusher screws. In

the Curtiss machine the power plant was placed back of the aviator and mounted approximately in the center of the gap so that the propeller thrust came about half-way between the upper and lower wing surfaces. In this machine the power transmission system was very much simplified by having the propeller directly connected to the engine crankshaft and revolving it at engine speed.

Another marked difference was in the method of securing lateral stability, as in the Wright machine the wing tips were made flexible, and it was possible to warp them so that the wing curvature at the tip and for a

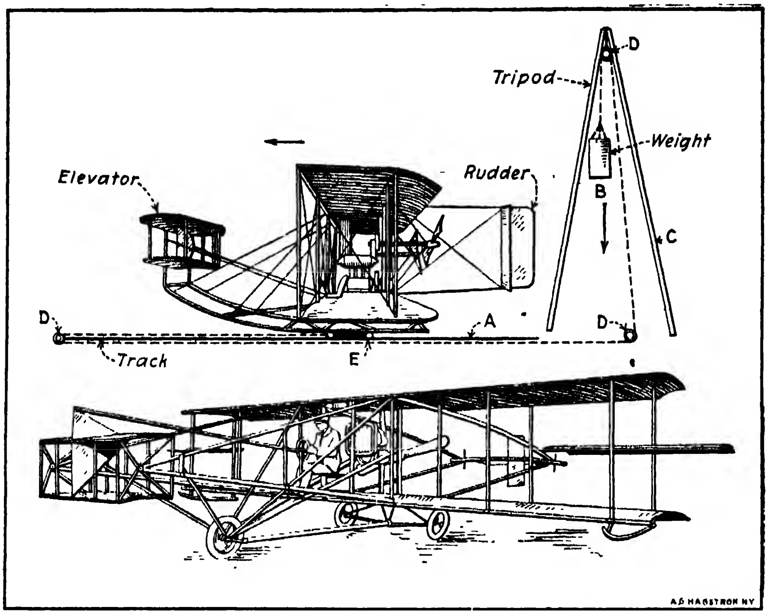


Fig. 79 A and B.—Two Early Biplanes, that at the Top Being the Historic Wright Machine which Demonstrated the Possibilities of Mechanical Flight. The Lower One is an Early Curtiss Machine of Remarkably Dependable Characteristics.

certain distance toward the center was changed so that on the high wing one had a decreased curvature and a lessened lift, while on the low wing one had a more pronounced camber and a correspondingly increased lifting effect. In the Curtiss biplane lateral stability was secured by means of small auxiliary wings or ailerons attached to one of the wing spars and so connected to a shoulder yoke that the pilot could incline his body toward the high side of the machine and by so doing regulate the position of the aileron on the high side so as to give a depressing action, while that on the low side was tilted so that a lift on the under surface would give a greater lifting effort and consequently tend to right the machine. In both of the early biplanes shown, the elevator was in the form of a small biplane structure and was carried by outriggers at the front end of the machine. The vertical rudders by which the machines were steered from side to side were carried at the back in both types.

The early type of Bleriot monoplane shown at Fig. 79 C had a wheeled landing gear and was a remarkably efficient and light airplane for its time

Fig. 79 C.—The Bleriot Monoplane, an Early Type, First to Cross the English Channel.

Balancing was by wing warping according to the Wright principles. The single surface aerofoil was of thin wing section so it had to be thoroughly braced by both flying and landing cables. This machine took off readily on its wheel gear and was easily maneuverable and fast. It won various competitions in this country, piloted by Claude Grahame-White, an English aviator and Earl Ovington, a pioneer American pilot.

The most marked difference in which the two pioneer types of biplanes differed and which had a material bearing on the design was in the matter of starting. The first early Wright machines used a system of launching the airplane which permitted it to rise in a preliminary run of a little less

than 75 feet, but it involved a rather elaborate launching mechanism, and if the airplane landed at a point remote from the launching gear it could not ascend again. The foreign designers and Curtiss in this country believed that the wheel type landing gear would be the most practical even if it did involve a run of several hundred yards over the ground before sufficient flying speed was obtained to enable the airplane to rise in the air. The system originated by the Wrights is not used at the present time in connection with machines starting from inland flying fields, but is utilized in a modified and improved form for launching seaplanes from the decks of ships. Even the Wright Brothers soon changed their construction to a combined wheel and skid landing gear and took off from the ground by the thrust of the propellers alone.

Early Wright Starting System.—The form of starting apparatus adopted by the Wrights on their first creation depended upon the rapid acceleration given by a heavy falling weight. The airplane was mounted on a small wheeled truck which ran on a track. A rope was attached to the truck and ran through sheaves and over a pulley, supported on a high tripod, and a heavy weight was attached to the rope, so that when it was released and fell, it would draw the small truck along the track and the airplane would be travelling at sufficiently high velocity by the time it reached the end of the track, so that the air under the wings and the revolving air screws were delivering enough thrust to lift the machine into the air. This was the original form of catapult landing gear which has been greatly perfected by the U. S. Navy for launching airplanes from battleships. With this construction it is possible to use skids for an alighting gear which form part of the framework of the airplane. Another thing made possible by this method of launching was the fact that a smaller amount of surface and reduced engine power could secure flight. This type of construction was not encouraged because with wheels one is independent of starting platforms, rails, or catapult launching devices, and for this reason the wheel landing gear became universally applied and is now used on all land machines.

One of the advantages brought up for the skids was that they acted as a brake and retarded the airplane movement after it touched the ground, whereas the wheel form did not enable the aviator to make a quick landing. This resulted in a number of landing gear designs in which wheels and skids were combined, though these gears weighed more than the types in which the wheels alone were used. In the early Curtiss machines the motion was arrested by a simple spoon brake actuated by the foot and working on the tire of the front wheel, this serving to arrest motion over the ground soon after the plane alighted and in recent machines we find this same principle applied to brake drums attached to the wheels which house internal expanding brake shoes.

In the early Curtiss machines no shock absorbing means other than that provided by the resiliency of the tires was incorporated in the construction. In the first Bleriot monoplanes, which were so efficient a flying machine that their construction is followed in many respects in the later types of planes, the two-wheel alighting gear was provided with shock absorbing means in the form of coil springs on the early machines, which

construction was afterward modified to use shock absorbers of rubber. A discussion of some of the modern type of alighting gears to follow will show how these gears have been simplified, strengthened and improved in action.

Design of Fuselage Framework.—One of the disadvantages of either of the machines shown at Fig. 79 in which the power plant was placed either at the side or in back of the aviator, was that in event of a rough landing, which was much more common in the early days than it is at the present time, the aviators were very often fatally injured by having the power plant fall on top of them in nearly every smash. It was soon discovered that the system of construction employed on the Bleriot monoplane had the marked

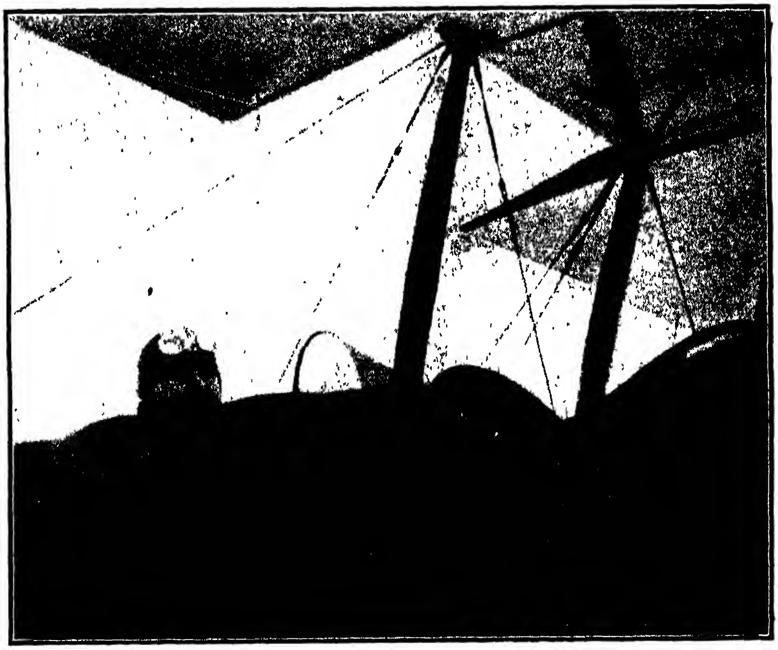


Fig. 80.—Major Victor W. Page Seated in Rear Cockpit of Modern Tractor Biplane Showing Degree of Protection Offered and Space Available for Pilot.

advantage of making a machine "nose heavy" and that in most rough landings the position of the power plant was such that it fell clear of the aviator in event of a smash which were frequent in the early days and that a considerable degree of protection was afforded by the landing gear and supporting framework.

One of the most important parts of the modern airplane is the framework supporting the sustaining surfaces and employed to carry the greater part of the weight, such as the power plant and the useful load. The problem of building a fuselage or frame sufficiently light for use in airplanes where every ounce must be accounted for, while at the same time it would possess the strength and endurance essential for this work was not difficult of solution because light and strong materials were available that were particularly well adapted to airplane framework construction and

much of the engineering data pertaining to bridge and truss structure could be depended on as a basis of computations in designing the airplane fuselage structure.

The form of the machine has a material bearing upon the general lines of construction as will be evident by examination of the airplane types shown at Fig. 79 when compared to those of more modern design. In the modern construction the fuselage is the main member from which the surfaces extend, and in the modern monoplane the fuselage may be compared to the body of a bird and the aerofoils to the wings. It was soon learned, as a result of the wind tunnel experiments, that air resistance was materially less when the closed-in fuselage frame was used instead of the open framework and outriggers provided in the early forms of biplanes. A reduction in air resistance made greater speed possible with the same power and reduced the supporting surface necessary to secure sustentation, or increased the load carried without a corresponding augmentation of wing area.

Fundamental Design Considerations.—In designing any form of airplane or component thereof the designer must have certain basic principles in mind. These were stated in the writer's first treatise on aerial navigation published about seventeen years ago, and are still applicable to the design of modern forms. The following are principles which should be observed in designing or building airplanes.

1. An airplane must have sufficient combined speed, power and plane area to raise a useful load in addition to its own weight. The greater the amount of useful load lifted for a given engine power the greater the efficiency of the airplane.

2. The greater the speed of flight the less the plane surface required and the smaller necessary angle of incidence of that plane for carrying the load.

3. To counteract the resistance set up by the means of gaining momentum while on the ground, which is additional to the resistance the machine will have when once it is clear of the ground: (a) extra power is required or (b) extra plane surface to meet the power available or (c) a better lifting effect for the plane area and power we have available or (d) an outside agency that will assist in launching the plane. Though extra power means more weight and extra supporting area means more resistance, the modern airplanes nearly always have a reserve of power, as it has not been possible to make any radical improvements in the present methods of construction.

4. The supporting planes must always have sufficient area to permit a reasonable and therefore a safe landing speed, or means must be provided to secure the same effect if wing spread is reduced.

5. The shape, camber and angle of incidence to be employed depend upon the type of machine to be constructed and the means employed for obtaining lateral and longitudinal balance and stability. We have seen that a plane suitable for carrying heavy loads is not a form adapted for high-speed work.

6. All parts of the machine should be constructed of as strong material as possible, and the design should be such that the part should create as little

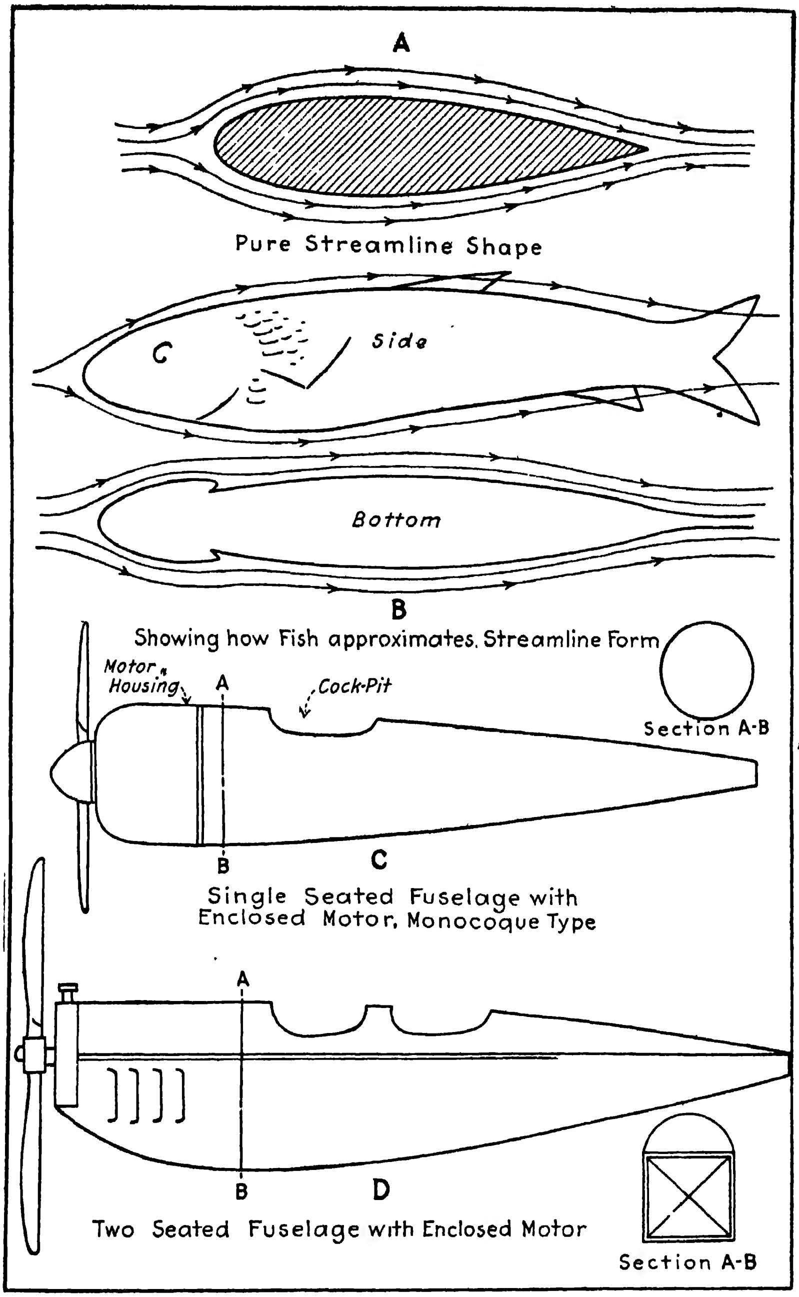


Fig. 81.—Illustrating the Development of the Modern Fuselage from Studies Made of the Streamline Shape of the Fish.

useless or parasitic resistance as possible. The general arrangement should be simple and the control should be easy of manipulation.

7. The machine should be so designed that it will be inherently stable to some degree; it should have an ample margin of safety and as large a gliding angle as possible.

Reduction of Parasitic Resistance.—One of the important points in which the modern airplane has been improved has been in the elimination of parasitic resistance. This has been accomplished by a careful study of air resistance on bodies of various forms made in the wind tunnel. While the action of air around a streamline body has been previously shown, it may be well to review the definition of this form of body. As shown at Fig. 81 A, a streamline body may be defined as one which when moving through a fluid or when a fluid is moving past it that does not cause a breaking up of the air stream nor produce any disturbance or eddy currents in its wake. It should be of such a form that the streamlines or air currents would be deflected in a gradual manner and which would merge in parallel streams at the rear of the body with practically no loss of energy.

Tests that have been made with bodies of various forms in water which, of course, offers considerably more resistance to the movement of a body through it than the air does, have demonstrated that nature has worked out very efficient streamline shapes which were found incorporated in the various species of fish. If one will refer to the illustrations at Fig. 81 B, which show the side and bottom views of a very fast-swimming fish, the trout, it will be observed that it follows very closely an ideal streamline shape as shown at A. An important consideration in the design of streamline form is in the fineness ratio. This is the ratio the total length bears to the greatest width. In the trout the length is from six to eight times the greatest width. Streamline bodies for use in air can be less fine than those intended to be forced through the water and at equal velocity. For example, the Zeppelin types of rigid airships had a fineness ratio of 5.8 as shown at A Fig. 82. In more recent designs of large aircraft of the dirigible type this fineness ratio has been reduced to 3.4 without reducing the aerodynamical properties and greatly increasing the strength of the internal framework structure. A fineness ratio of 3.4 means that the greatest diameter is such that the length has 3.4 times its value.

Naturally, airplane designers plan the airplane fuselage with a view to approximating as nearly as possible and ideal streamline body which, however, had to be modified owing to structural considerations. The ideal shape for an airplane fuselage is that of a streamline body that has sufficient capacity to accommodate the engine, fuel tanks, aviators and the necessary accessories without being excessively wide. The fineness ratio of airplane fuselages of present-day types is about seven to one in the average example. This means that the fuselage is about seven times as long as its width at the widest part.

Airplane Fuselage Forms.—The airplane fuselage is made in two main forms. In that shown at Fig. 81 C we have what is called the "monocoque" type and which has less resistance than any other form, and is therefore used on fast machines. In this the fuselage is approximately round in cross-section, its shape depending on the type of power plant employed and the disposition of the power plant with auxiliary parts. Experiments have shown that at 60 miles an hour a true streamline body measuring 3 feet in diameter by 17 feet in length would have a resistance estimated at about 7 pounds. The usual airplane body resistance varies from 30 to 60 pounds at the same speed, and this is due to the structural

requirements in the airplane which called for radiators in an exposed position, wind deflectors and a departure from the true streamline form on account of having to carry a pilot and a passenger. The fuselage at Fig. 81 D shows the form of fuselage provided on practically all two-place machines. A fuselage of the single-seated "monocoque" type having a revolving motor in a rounded housing might have a resistance of about 30 pounds. That of a two-place fuselage such as shown at Fig. 81 D might run up to 60 pounds. The greater resistance makes the form of fuselage

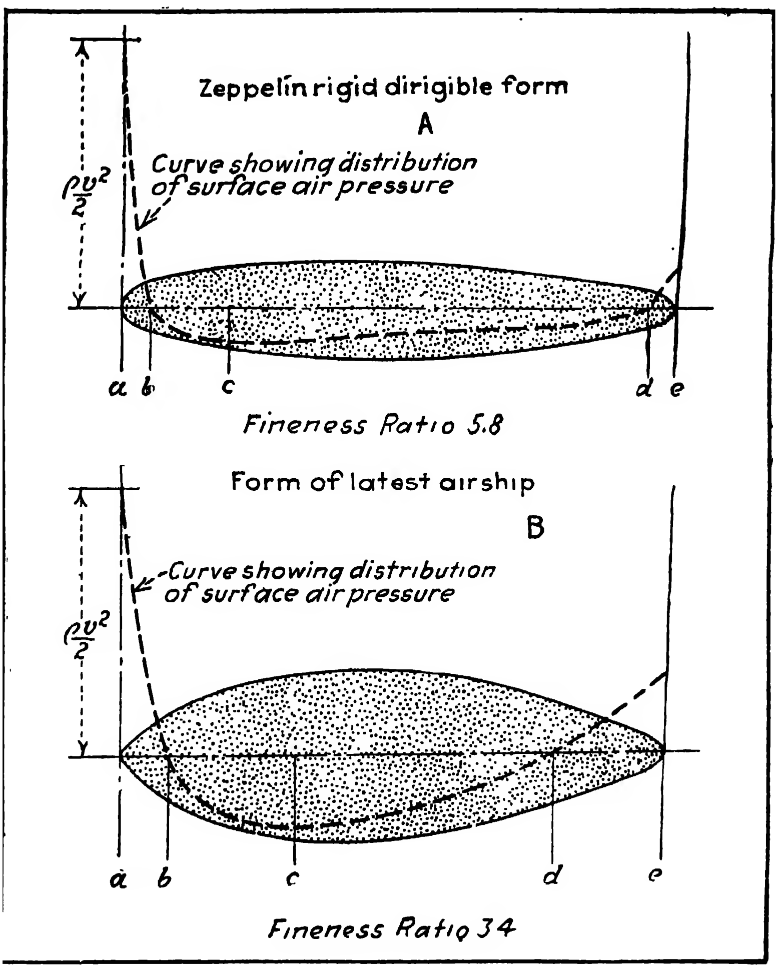


Fig. 82.—Distribution of Surface Air Pressure over Airship Hulls in Motion. A—Zeppelin Rigid Dirigible Form. B—Shape of Gas Bag of Lätest Airships. Note Influence of Fineness Ratio on Distribution of Surface Air Pressure.

shown at D, a type that is adapted to moderate speed machines, while the monocoque body construction shown at C, due to its offering about half the resistance, is the type most suited to high-speed, single-seat planes.

Complete Enclosure Important.—In the early days it was not thought necessary to enclose anything but the front part of the fuselage, as it was

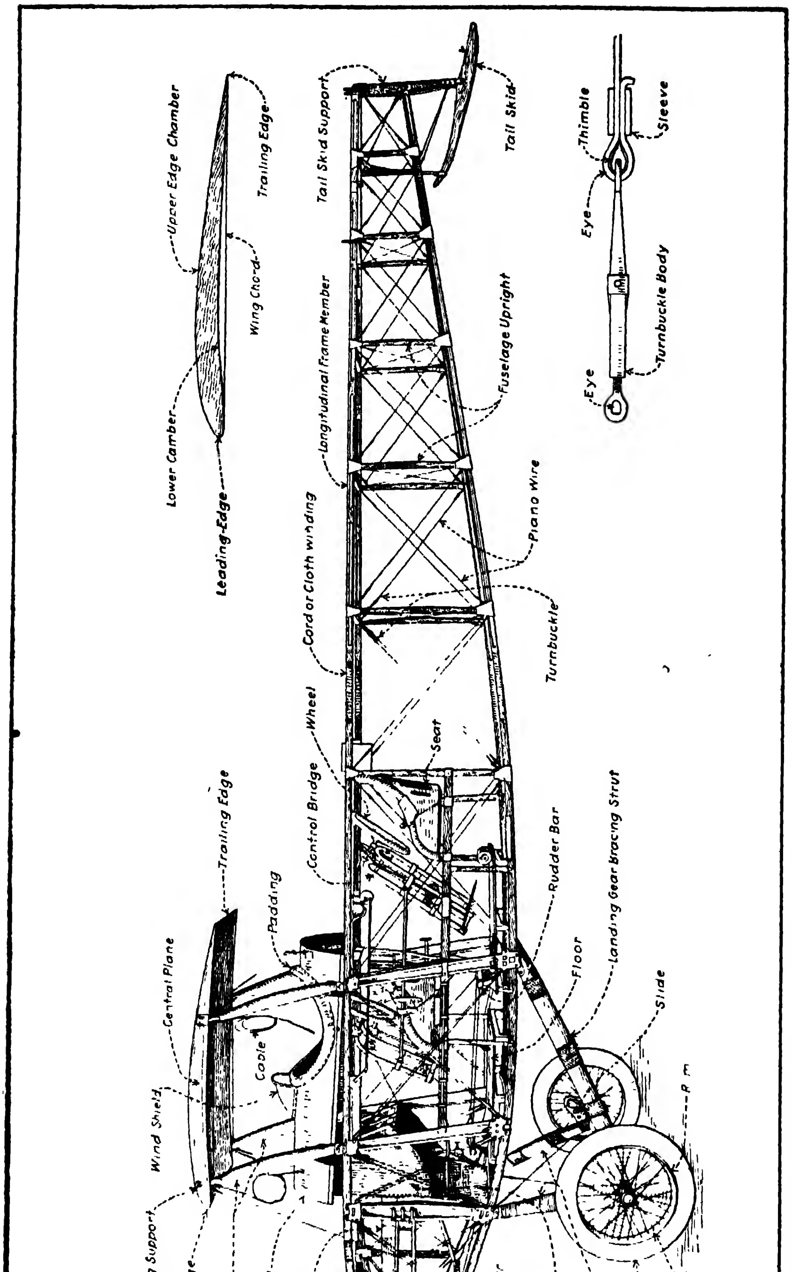


Fig. 83.—A Fuselage of the Wood and Wire Truss Type Used on Curtiss JN 4 Airplanes, Showing Construction of Landing Gear and Substantial Bracing where Greatest Weight and Stress Occurs. This is Fitted with Dual Dep Control.

believed that the resistance of the open framework at the back would be negligible. Experiments soon demonstrated that there was a marked reduction in the resistance if the framework of the fuselage was entirely

covered in with linen instead of only half covered. Early fuselage forms with the covering removed are shown at Fig. 83 and Fig. 84. It will be observed that this type of fuselage consists essentially of four longerons or longitudinal frame members of ash which are held apart by fuselage uprights of ash or spruce and kept separated by compression members of corresponding form. These wooden spacing and bracing members are attached to metal fittings and the entire structure is braced by cross wires. At the front end of the fuselage, where the greatest load is carried, the bracing is with flexible cable, while at the back end, where the section of the fuselage is smaller and where the load carried is less, single-strand or piano-wire braces are all that is necessary. The front end of the fuselage terminates in a steel stamping or spider which not only serves to tie all of the longitudinal frame members together, but which serves also as a radiator support and an anchorage for the front end of the engine bed timbers. In the fuselage, the uprights at that point in the frame where the greatest stress comes are of substantial proportions.

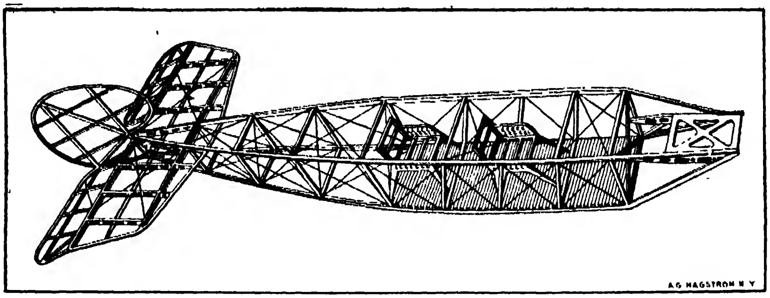


Fig. 84.—Showing a Truss Type Fuselage without the Covering and Illustrating the Methods Employed to Get Great Mechanical Strength with a Minimum of Weight by Using Wood and Wire.

Wood and Wire Truss Construction.—The construction of a typical truss construction fuselage used on a wartime biplane and its relation to the rest of the structure is clearly outlined in Fig. 85. This is built-up of wooden longitudinals separated by vertical compression members and with diagonal braces at that portion where the gunner's cockpit is situated. Plywood flooring is used. The engine support, as shown at B is built of steel tubing of cantilever beam form, being attached at the base to fittings on the front of the wooden fuselage. The view at B shows the fuselage completed by the installation of the power plant unit, the center section to which the aerofoils are attached and the landing gear. The rear portion of the fuselage has been covered with fabric. In the view of the airplane structure at C, the control surfaces at the rear and the wing structure has been added.

It will be apparent that in this construction, as in that shown at Fig. 83, that considerable reliance is placed on the bracing effect of wire cables and metal fittings at the points of attachment of the various structural members. For convenience in design and erection the fuselage is divided into stations, these being numbered consecutively as shown at A. After the various longerons and spacing members secured together with metal

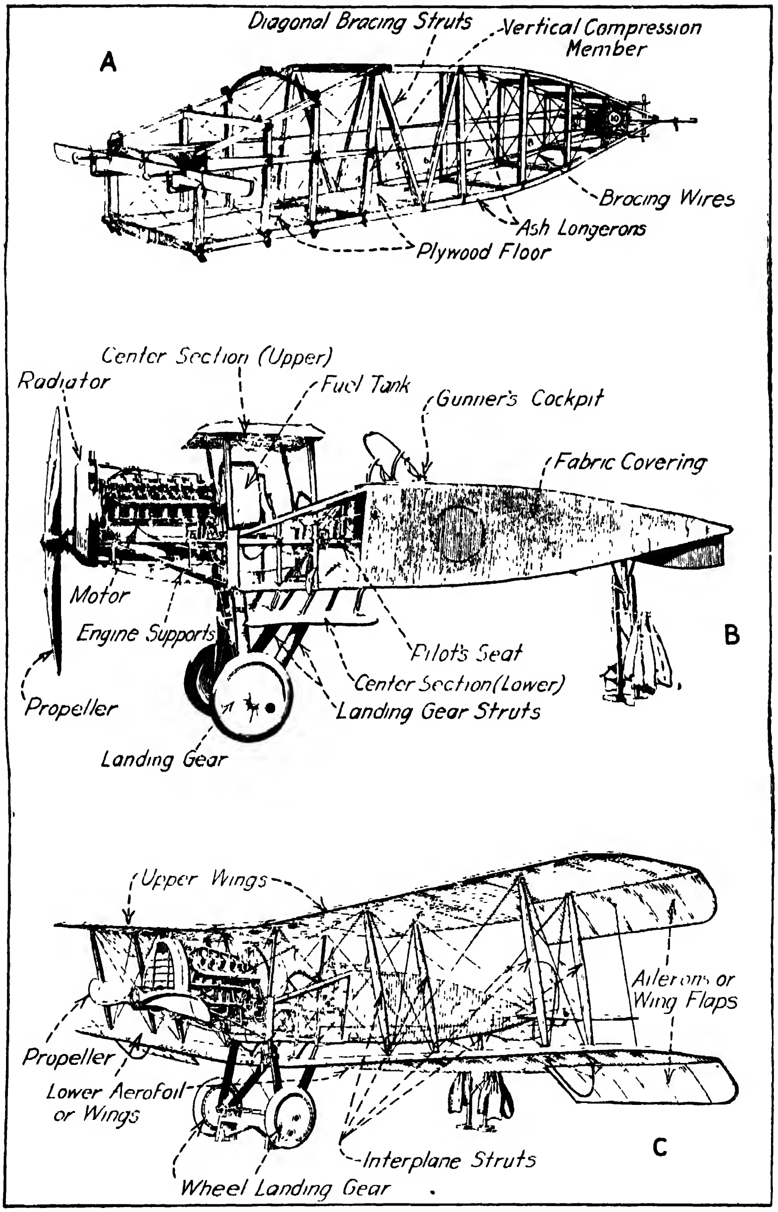


Fig. 85.—Diagrams Showing Steps in Assembling Biplane Using Wood and Wire Truss Type Fuselage. A—Fuselage Being Lined Up. B—Fuselage with Covering, Center Section, Landing Gear and Power Plant Installed. C—Airplane Practically Complete after Biplane Wing Cellules are Attached to Center Section.

fittings and small through bolts, the structure is trued-up by adjusting the tension of the cross-bracing wires. This process will be described in proper place. The fuselage structure of a large bombing plane is shown at Fig. 86, and it will be apparent that the greater load it must carry is provided for by a much deeper section and the use of more vertical and diagonal bracing. Attention is directed to the complete system of wire

bracing, which makes the entire structure a truss of great strength in proportion to its weight.

Composite Fuselage Construction.—A bulkhead and plywood skin construction has also been used for airplane fuselage construction and composite structures have been evolved in which the open truss and the plywood skin methods have been used together. The fuselage at Fig. 87 shows a composite construction. The structure is composed of three sections, the front being the largest and longest. As the front view indicates bulkheads or frames of laminated wood attached to longerons form the framework to which the plywood skin is attached. The intermediate section is of the truss form, while the tail section is also of the truss form covered with plywood. Steel fittings are used for securing the wing spars and landing gear struts to the fuselage. The various sections are held together by reinforcing straps of metal and bolts passing through the longerons and internal bracing wires take some of the load from the straps.

Plywood Fuselage.—Plywood in fuselage construction may be used merely as covering, or as reinforcement for a truss that is designed to carry either the entire load or a large portion of it as shown at Fig. 87. Or, if the fuselage is of the all-veneer type, the plywood shell itself, strengthened by the longerons, carries all the load as in the form shown at Fig. 89.

When plywood is used in conjunction with a fuselage truss it is important that it should not wrinkle or buckle. This tendency is more pronounced when the plywood has to lie flat than when it is curved. To decrease wrinkling or similar distortion, the core of the plywood is made relatively thick, and of a low density wood like poplar or basswood, while the face plies are of thin mahogany or birch. In the first application of plywood to fuselage trusses it served merely as a covering to replace linen. Any strengthening it afforded was incidental and was neglected in computing the longerons and wires of the truss. This was of course uneconomical. In later designs the plywood was made slightly heavier and stiffer, and could therefore be depended upon to carry shear stresses, to afford lateral support to compression members, and to bind together and stiffen the entire truss. It was found that all diagonal bracing wires could be omitted and the size of the longerons considerably decreased. The use of diagonal struts, running from the lower longeron at the points of attachment of the chassis struts and flying wires, to distribute the stresses from these members to several points on the upper longeron, is advisable. The ease with which a fuselage of this character can be built, together with its comparative lightness, makes it a close competitor of the newer, all-veneer body.

One of the chief advantages of the latter type is its high aerodynamic efficiency due to the excellent streamlining that can be obtained, and to the fact that changes in the attitude of a plane do not sensibly increase the resistance of such a faired body. In the veneer fuselage, the skin resists all the vertical and horizontal shear, and together with the longerons, it carries the bending moment produced by air loads on the tail surfaces or by dynamic loads. This second function determines that the grain of the face plies shall be longitudinal with respect to the axis of the body, and that of the core, transverse.

Spruce plywood because of its lightness and stiffness has given excellent

results, particularly in designs of fairly good depth and moderate length. But for the fuselages of larger, heavier planes, especially those which are relatively shallow or unusually long, a stronger wood such as elm or birch is better. In many instances a combination of elm faces and basswood core is most suitable.

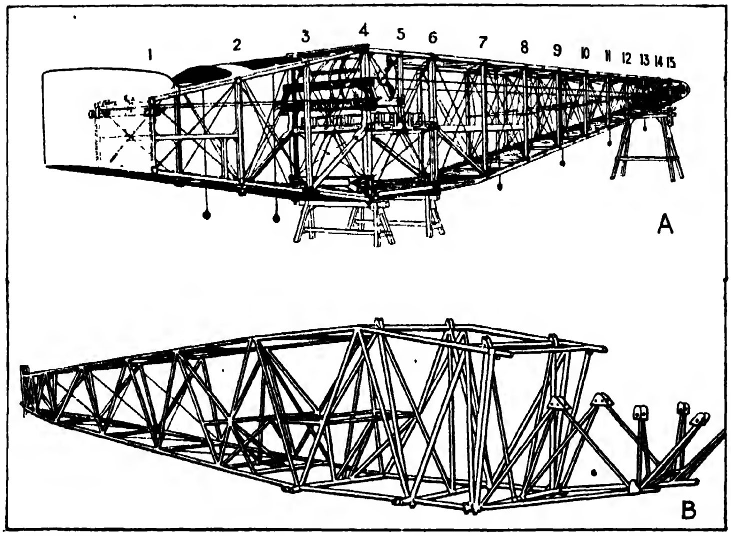


Fig. 86.—Comparing Two Different Types of Fuselage. A—Wood and Wire Truss Construction Employed on Large Bombing Planes. Note Numbering of Stations to Facilitate Assembly and Lining Up. B—Metal Tube Fuselage of Pitcairn Fleetwing Five Place Transport Biplane.

Since the bending moment increases rapidly forward of the rear cockpit, it has been found economical to use more plies in the part of the fuselage extending from just aft of the rear cockpit forward to about the center of the engine section, than in the rear portion of the body. In a comparatively heavy fuselage, for example, this rear section is usually of three-ply veneer and the critical section forward of the rear cockpit, of five-ply. The purpose of the heavy construction near the engine section is to resist the great shearing stresses produced by the engine and fuel tanks. Where the outer plies become unnecessary they taper down to a feather edge. For smaller bodies the skin is three-ply at the critical section, and toward the rear two-ply. In this case fabric often is used between the plies because of the greater toughness and stiffness that it imparts to the skin.

With this general type of fuselage the skin is divided into four longitudinal sections, the top, bottom, and sides. These sections may in turn be spliced transversely at one or more points. The chief function of the top and bottom portions of the skin is to resist bending moment, that of the side sections, to resist shearing stresses. The longitudinal sections join at the longerons to which the plywood is glued, and screwed or nailed. A scarf joint is considered superior to a butt joint, largely because it stands weathering better. In making transverse splices in the plywood it is the best practice to employ a long, glued scarf joint having a slope of approxi-

TABLE IX

Tentative Table of Strengths of Various Species of 3-Ply Panels.

All plywood was 3 ply with the grain of successive plies at right angles.
All plies in any one panel were of the same thickness and of the same species. Eight thicknesses of plywood ranging from 3/30" to 3/6" were tested.

Species	Av. Sp. Gravity of Ply-wood†	Av. percent Moisture	Column Bending Modulus *Parallel No. of Tests	Column Bending Modulus *Parallel Lbs. per sq. in.	Column Bending Modulus *Perpendicular No. of Tests	Column Bending Modulus *Perpendicular Lbs. per sq. in.	Tensile Strength *Parallel No. of Tests	Tensile Strength *Parallel Lbs. per sq. in.	Tensile Strength *Perpendicular No. of Tests	Tensile Strength *Perpendicular Lbs. per sq. in.	Split. No. of Tests	Resistance Percent of Birch resistance	Modulus of *Parallel Lbs. per sq. in. in bend'g	Elas'c'ty *Perpend. Lbs. per sq. in. in Bend'g
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Birch, Yellow..........	.67	8.5	195	16,000	200	3,200	200	13,200	200	7,700	400	100	2,259,000	197,000
Ash, Black........	.48	9.2	80	7,360	80	1,620	80	6,200	80	3,940	160	68	1,028,000	87,000
Ash, Commercial White	.61	10.6	160	9,980	160	2,640	160	6,540	160	4,330	320	72	1,422,000	144,000
Basswood	.41	9.6	160	6,520	160	1,540	160	6,300	160	4,100	320	65	1,213,000	85,000
Beech	.67	8.6	120	15,390	120	2,950	120	13,000	120	7,260	240	76	2,149,000	167,000
Cedar, Spanish.........	.41	13.3	115	6,460	115	1,480	115	5,200	115	3,340	230	60	1,032,000	84,000
Cherry	.49	9.9	40	11,180	40	2,220	40	6,920	40	5,650	80	86	1,448,000	150,000
Chestnut	.43	11.7	40	5,160	40	1,110	40	4,430	40	2,600	80	74	744,300	75,000
Cottonwood	.48	9.5	40	8,110	40	1,660	40	7,540	40	4,500	80	94	1,461,000	110,000
Douglas Fir	.45	8.4	105	8,890	110	1,730	110	5,630	110	3,530	220	59	1,316,000	129,000
Elm, Cork............	.59	11.7	35	10,530	35	2,160	35	9,840	35	6,040	70	100	1,729,000	125,000
Elm, White...........	.53	8.9	120	8,810	120	1,990	120	6,460	120	4,190	240	85	1,230,000	112,000
Gum, Red............	.54	8.5	102	9,330	102	1,830	102	7,780	102	4,890	204	68	1,487,000	107,000
Gum, Cotton..........	.49	10.3	80	7,770	80	1,580	80	6,260	80	3,770	160	60	1,300,000	111,000
Gum, Black...........	.54	10.6	40	8,090	40	1,920	35	6,960	35	4,320	70	55	1,275,000	113,000
Hackberry	.54	10.9	40	8,380	40	1,720	40	7,870	40	4,550	80	85	1,257,000	111,000
Hemlock	.49	9.2	40	9,520	40	2,120	40	7,490	40	4,740	80	65	1,614,000	120,000
Maple, Soft...........	.60	9.0	80	11,750	80	2,430	80	8,020	80	5,470	160	114	1,822,000	147,000
Maple, Hard..........	.68	7.6	82	15,870	82	3,320	82	11,610	82	7,060	164	124	2,009,000	186,000
Mahogany, True.......	.48	11.4	35	8,500	35	1,940	35	6,390	35	3,780	...	...	1,252,000	117,000
Mahogany, African.....	.52	12.7	20	8,070	20	2,000	20	5,370	20	3,770	...	...	1,261,000	144,000
Mahogany, Philippine..	.53	10.7	25	10,160	25	2,310	25	10,670	25	5,990	50	90	1,820,000	169,000
Magnolia	.59	9.9	40	9,830	40	2,340	40	10,000	40	5,740	80	98	1,704,000	135,000
Oak, White...........	.64	10.1	75	9,440	75	1,920	75	7,260	75	3,950	150	90	1,085,000	106,000
Oak, Red.............	.59	9.3	115	8,590	115	2,070	115	5,480	115	3,610	230	80	1,289,000	120,000
Pine, White...........	.43	10.2	35	7,920	40	1,770	40	5,640	40	3,870	80	52	1,274,000	99,000
Poplar, Yellow........	.50	9.0	120	8,900	120	1,920	110	7,380	120	4,520	240	52	1,501,000	114,000
Redwood	.41	11.2	65	7,900	65	1,500	65	5,100	65	3,000	130	48	1,211,000	118,000
Sycamore	.56	10.0	80	10,920	80	2,390	80	8,840	80	5,480	160	79	1,642,000	135,000
Spruce, Sitka..........	.41	8.0	63	7,280	63	1,540	63	5,180	63	3,150	126	75	1,176,000	98,000
Walnut, Black.........	.58	9.7	80	11,850	80	2,660	80	7,640	80	5,100	160	77	1,664,000	144,000

*Parallel and perpendicular refer to the direction of the grain of the faces relative to the direction of the application of the force.
†Spec. Gravity based on oven dry weight and volume at test.

mately 1 to 25, which with 3/32 inch plywood, for example, forms a lap of about 2½ inches. Such a joint would usually be made at a bulkhead. The plywood skin is attached to a frame as shown at Fig. 88, which shows the structure on the assembling jig.

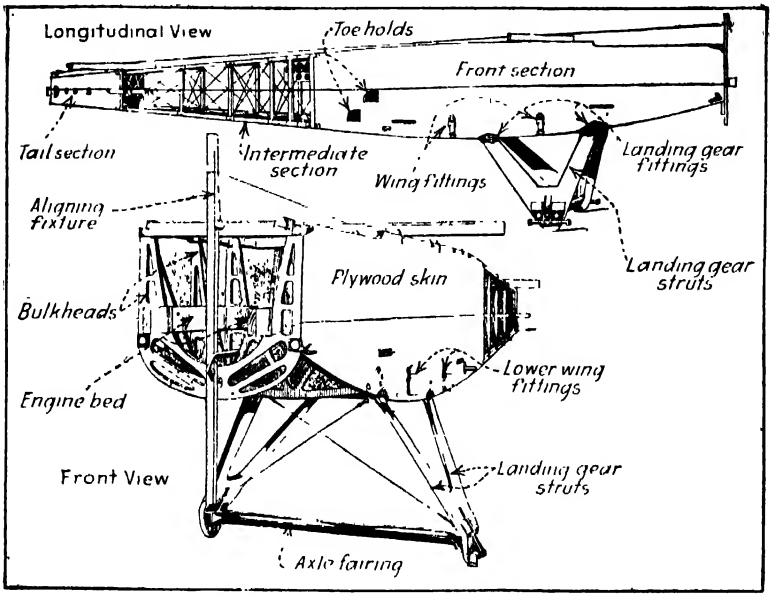


Fig. 87.—Front and Longitudinal Views of Composite Fuselage Employed on DH 4 Airplanes.

The veneer or plywood fuselage shown at Fig. 89 was tested at McCook Field, Dayton, Ohio and interesting conclusions were reached by the Army engineers making the tests. This fuselage, tested, without wing anchorage fittings, weighed 163 pounds, as follows:

Bulkheads	40 lbs.
Longerons	25 lbs.
Incidentals	34 lbs.
Skin	64 lbs.
Total	163 lbs.

The veneer covering had spruce face plies with the grain longitudinal throughout and also had layers of cotton fabric between all plies. As in the previous type the skin was not the same throughout the whole fuselage, but varied from 1/16 inch for the first ply, then 1/24 inch thick for the second ply and 1/16 inch ply for the third layer. The rear section was made of three plies of 1/24 inch thick veneer. The covering was fastened to the bulkheads and longerons with nails and Certus cold glue.

There seems to be no doubt that veneer fuselages can be built for greater strength and a lighter weight than the standard wire truss type. They are an excellent production proposition, and would seem to merit wide adoption. It is a comparatively simple matter to obtain a good

streamline form in making veneer type fuselages, whereas to accomplish the same results in a truss type would necessitate building up a considerable false fairing. Veneer type fuselages maintain their alignment automatically under any load short of that which would cause absolute failure. There are other minor advantages in veneer fuselages, some of which have been mentioned previously and need not be gone into again.

The principle recommendations made by the U. S. Army engineers resulting from tests of the veneer type fuselages are as follows:

(1) The veneer skin should be made with a large proportion of grain longitudinal and with the face plies of hardwood.

TABLE X

Tensile Strength of Plywood and Veneer.

Species	No. of Tests	Moisture at Test — %	*Sp. Gravity of plywood	†Tensile Str. of 3-ply wood parallel to grain of faces Lbs. per sq. in.	¶Tensile Str. of single ply veneer—1½ (d) Lbs. per sq. in.
	(a)	(b)	(c)	(d)	(e)
Birch	200	8.5	.67	13,240	19,860
Ash, Black	80	9.1	.57	6,200	9,300
Ash, Commercial White	120	10.5	.61	6,700	10,050
Basswood	160	9.6	.41	6,300	9,450
Beech	120	8.6	.67	13,000	19,500
Cedar, Spanish	80	11.8	.43	5,220	7,830
Cherry	40	9.9	.49	6,920	10,380
Chestnut	40	11.7	.43	4,430	6,640
Cottonwood	40	9.5	.48	7,540	11,310
Douglas Fir	110	8.4	.45	5,630	8,440
Elm, Cork	35	11.7	.59	9,840	14,760
Elm, White	120	8.9	.53	6,460	9,690
Gum, Red	102	8.5	.54	7,780	11,670
Gum, Cotton	80	10.3	.49	6,260	9,390
Maple, Soft	80	9.0	.60	8,020	12,030
Maple, Sugar	82	7.6	.68	11,610	17,420
Oak, Red	115	9.3	.59	5,480	8,220
Oak, White	75	10.1	.64	7,260	10,890
Poplar, Yellow	80	8.8	.50	7,130	10,690
Redwood	65	11.2	.41	5,100	7,650
Sycamore	40	10.2	.56	9,180	13,770
Spruce, Sitka	40	7.9	.41	4,900	7,350
Walnut, Black	80	9.7	.58	7,640	11,460
Pine, White	40	10.2	.43	5,640	8,460
Mahogany, Philippine	25	10.7	.53	10,670	16,000
Mahogany, True	35	11.4	.47	6,380	9,570
Mahogany, African	20	12.7	.52	5,370	8,060

*Specific gravity based on oven dry weight and volume at test.
†Based on total cross sectional area.
¶Based on assumption that center ply carries no load.
Data based on tests of three ply panels with all plies in any one panel same thickness and species.

TABLE XI

Thickness Factors for Veneer.

Giving:

(a) Veneer thickness for same total bending strength as birch.
(b) Veneer thickness for same weight as birch.

Species	G* Av. Sp. Gravity of species from Bulletin 556 and other sources.	Specific Gravity of glued plywood as tested.*	Percent Moisture of plywood as tested.	S Unit bending strength compared with birch average of Cols. 5 and 7, Table 1 in percent of Birch.	Ks Thickness factor for the same total bending strgth. as Birch. $\sqrt{\frac{100}{S}}$	Kw Thickness factor for the same weight as birch. $\frac{.63}{G}$
1	2	3	4	5	6	7
Birch, Yellow	.63	.67	8.5	100	1.00	1.00
Ash, Black	.50	.48	9.2	47	1.46	1.26
Ash, Commercial White	.58	.61	10.6	66	1.23	1.09
Basswood	.38	.41	9.6	42	1.54	1.66
Beech	.63	.67	8.6	96	1.02	1.00
Cedar, Spanish	.34	.41	13.3	41	1.56	1.85
Cherry	.51	.49	9.9	70	1.19	1.24
Chestnut	.44	.43	11.7	33	1.74	1.43
Cottonwood	.43	.48	9.5	51	1.40	1.47
Douglas Fir	.44	.45	8 4	55	1.35	1.43
Elm, Cork	.66	.59	11 7	68	1.23	.95
Elm, White	.51	.53	8.9	56	1.33	1.24
Gum, Red	.49	.54	8.5	58	1.31	1.29
Gum, Cotton	.52	.49	10.3	49	1.43	1.21
Gum, Black	.52	.54	10.6	52	1.38	1.21
Hackberry	.54	.54	10 9	53	1.37	1.17
Hemlock	.42	.49	9 2	61	1.28	1.50
Maple, Soft	.48	.60	9 0	74	1.16	1.31
Maple, Hard	.62	.68	7.6	100	1.00	1.02
Mahogany, True	.49	.48	11.4	54	1.36	1.29
Mahogany, African	.46	.52	12.7	53	1.37	1.37
Mahogany, Philippine	.57	.53	10.7	65	1.24	1.11
Magnolia	.51	.59	9.9	63	1.26	1.24
Oak, White	.69	.64	10.1	59	1.30	.91
Oak, Red	.63	.59	9.3	55	1.35	1.00
Pine, White	.39	.43	10.2	50	1.41	1.62
Poplar, Yellow	.41	.56	9.0	56	1.33	1.54
Redwood	.36	.41	11.2	49	1.43	1.75
Sycamore	.50	.56	10.0	69	1.20	1.26
Spruce, Sitka	.38	.41	8.0	46	1.47	1.66
Walnut, Black	.57	.58	10.2	76	1.15	1.11

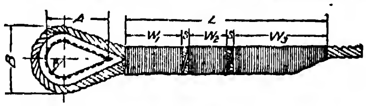
*Specific gravity based on oven-dry weight and volume at test.

(2) The use of real longerons is sound.

(3) The stiffening of the skin of a veneer fuselage with the usual disposition of bulkheads is not at all difficult. Excessively strong bulkheads are not required.

(4) When properly stiffened by bulkheads, the under side of the skin has a decided compression value, consequently it is not necessary to use excessively strong lower longerons.

Dimensions for Typical Lap Splices in Different Sizes of Cables



Diameter of cable in	Dimensions in inches							
	Splice	Space	Wind			Thimble		
	L	S	W_1	W_2	W_3	A	B	R
1/32	1 1/2	1/32	9/16	5/16	9/16	5/16	3/8	3/32
1/16	2 3/8	1/16	11/16	5/8	1	9/16	9/16	3/16
3/32	2 5/8	1/16	3/4	5/8	1 1/8	5/8	5/8	3/16
1/8	3 1/8	3/32	5/8	11/16	1 3/8	5/8	11/16	3/16
5/32	3 3/4	1/8	11/16	3/4	1 11/16	3/4	7/8	7/32
3/16	4	1/8	1 1/8	3/4	1 7/8	1	15/16	1/4

(5) The skin is considerably strengthened by the use of cotton sheeting between the plies.

(6) Care should be exercised to see that the joints or splices in the skin do not come at points of great stress.

(7) The upper longerons should be strengthened at cutouts such as the cockpits.

(8) Bulkheads should be so designed that they will stand up well under local reactions and bending moment applied by the lift wires.

(9) Very careful manufacture should be maintained, in order to insure good uniform results.

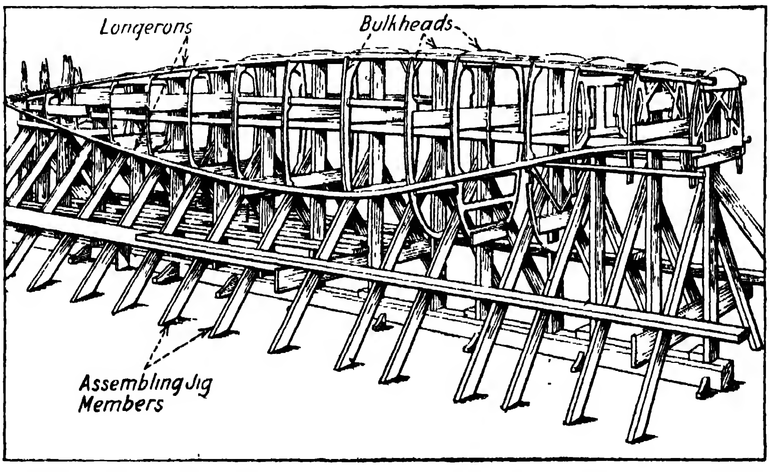


Fig. 88.—Bulkheads and Longerons of Veneer Fuselage Assembled in Jig for Application of Veneer Skin Covering.

Metal Fuselages.—The use of metal in fuselage construction is by no means a recent development as considerable application was made of alloy steel and duralumin tubes in wartime planes. The Brequet observation plane had a fuselage structure largely made up of tubing. When alloy steel tubing is used in connection with steel fittings in fuselage construction, the designer is given considerable choice of fastening means as the parts may be joined together by spelter by dip or flame brazing or the autogenous flame welding process may be employed. When duralumin

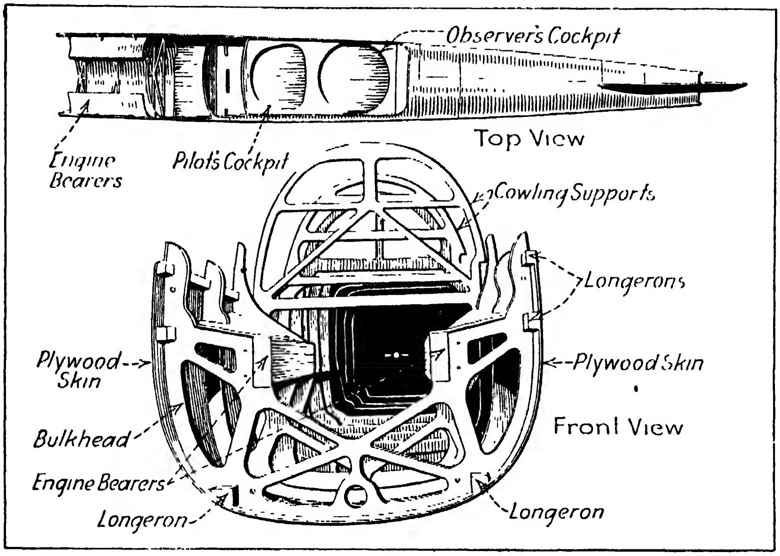


Fig. 89.—Top and Front Views of Veneer Fuselage Showing Important Structural Parts.

tubing is used, the ordinary spelter brazing is not practical owing to the degree of heat required so welding is resorted to in cases where mechanical fastenings, such as bolts and rivets or clamps cannot be used. Brazed joints should be carefully heat treated to insure against internal strains being present in the metal due to uneven expansion and contraction. With the autogenous welding flame, considerable care is required but not as much as when spelter brazing because the welding flame is small and heat is localized more than in brazing. All-metal fuselages have been made that compare very favorably with wood or composite construction and some have been made that weigh less than a wood fuselage of equal strength.

The front part of the Wright Apache plane fuselage used by the U. S. Navy shows how tubing can be used instead of wood for longerons and compression members or braces as well as struts. Tubing has the advantage over wood of having great tensile strength as well as high resistance to compression so bracing wires are not necessary when tubes of adequate diameter are used, as the members are adapted to resist both compressive stress and loads tending to elongate them. The method of joining the tubes is by welding to fittings An excellent example is the fuselage of the Pitcairn Fleetwing, a five place transport airplane, which is shown at Fig. 86

B. In order to save weight, however, it has been found that small diameter tubing supplemented by bracing wires is stronger than heavier, larger diameter tubing without them so metal fuselages are usually made as shown in illustration. The front part, from the pilot's seat forward is made of large diameter tubing without the bracing effect of tensioned cables and that portion of the structure back of the pilot's seat is of the truss construction with smaller diameter tubing and bracing wires. The fuselage is then faired with fabric, and the cockpit is well padded around the side and at the headrest, as shown at Fig. 91.

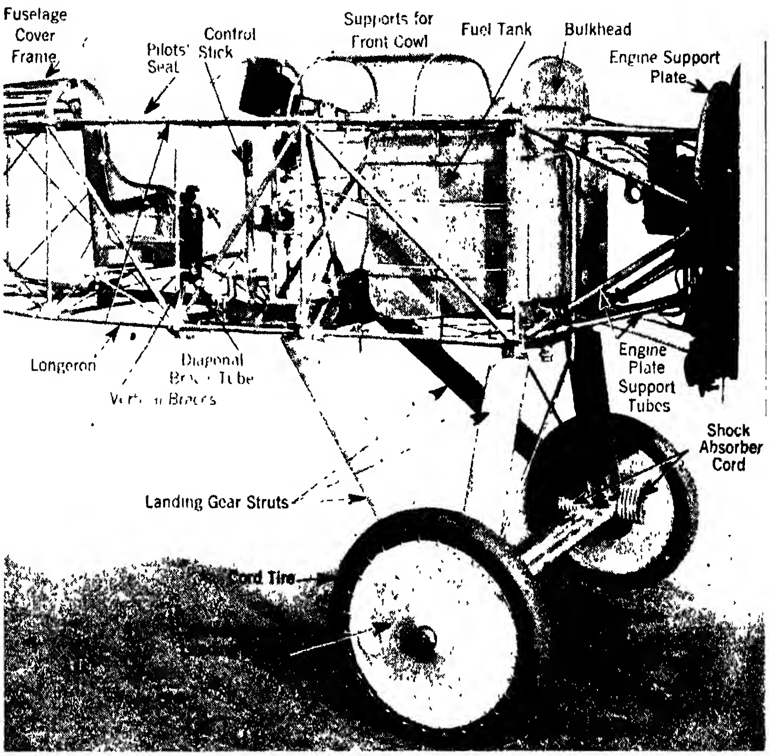


Fig. 90.—Front View of Wright-Apache Airplane Fuselage Showing Use of Metal Tubing for all Important Structural Members, also Depicting Location of Pilot's Seat and Control Stick, Placing of which Radial Cylinder Motor is Attached.

Duralumin.—This metal, so widely employed in aircraft construction is an aluminum alloy that fills a demand for a metal having the lightness of aluminum with strength and toughness usually associated only with ferrous metals.

Duralumin was first made in Germany and was developed by A. Wilm and associates during the years 1903 to 1914. The principal and unusual feature of this alloy is that after it has been hot, or hot and cold, worked, it can be strengthened and toughened further from 40 to 50 per cent by heat-treatment. This heat-treatment is somewhat analogous to that of the heat-treating alloy-steels, and consists of quenching from temperatures

below its melting point, followed by an aging process. The increased physical properties are not all produced immediately on quenching, but increase during the subsequent aging. In addition to being made in Germany, the manufacture of duralumin was taken up in England by Vickers, Ltd., prior to the late war. During that conflict its use for structural purposes in connection with aviation brought the material before the eyes of the engineering world. Today duralumin is recognized as occupying the same relative position to ordinary sheet or bar aluminum that heat-treated alloy-steel does to ordinary carbon-steel.

Duralumin is an aluminum alloy containing copper, manganese and magnesium. Its strength and toughness are comparable with those of mild steel, and are obtained with a specific gravity of 2.81 as against 7.80 for steel. The melting-point is approximately 655 degrees centigrade (1,211 degrees fahrenheit), the recalescence-point is 520 degrees centigrade (968 degrees fahrenheit), the annealing temperature is approximately 360 degrees centigrade (680 degrees fahrenheit) and the coefficient of expansion is 0.0000225 per degree of temperature centigrade (1.8 degrees fahrenheit). The chemical composition of the alloy varies within the following limits: copper, 3 to 5 per cent; magnesium, 0.3 to 0.6 per cent; manganese, 0.4 to 1.0 per cent; and the remainder is aluminum plus impurities. Small quantities of other metals are added sometimes for certain specific reasons. For instance, chromium can be added to increase the burnishing qualities of the metal.

The relative modulus of elasticity of duralumin is about one-third that of steel. The Bureau of Standards gives its value as being between 10,000,000 and 11,000,000 pounds per square inch. Steel is quoted generally as having a modulus of elasticity of 29,000,000 pounds per square inch.

In duralumin forgings where the sections are heavy, it is advisable to lower the minimum tensile-strength requirements to 50,000 pounds per square inch; a proportional increase in elongation will be found. Duralumin is unaffected by mercury, is non-magnetic, withstands atmospheric influences and offers a remarkable resistance to sea and fresh waters if properly protected. It does not tarnish in the presence of sulphureted hydrogen; and it takes a polish equal to nickel-plating and remains bright without cleaning longer than any plated or silvered article. It is the ideal substitute for aluminum, German silver, brass, copper, nickel-plated and silvered articles, and is the only substitute for steel where lightness combined with the strength of that metal is required. It is the only light metal that can replace steel in forgings, with a two-thirds saving in weight. Heat-treated duralumin forgings approximate mild-steel forgings in strength. Wherever weight is a deciding factor, duralumin is the most satisfactory metal for most shapes made by hot-working or forging. Naturally, duralumin forgings are especially desirable for reciprocating or moving parts where inertia, due to their own weight, forms a large part of the total stress. Duralumin machines and polishes very easily and, as it does not rust or corrode, it can be used in many places where weight is not the prime essential.

The manufacture of duralumin is somewhat analogous to that of steel and, in brief, is as follows:

(1) Manufacture of the alloy from its aluminum base
(2) Casting the ingot
(3) Hot-rolling or cogging in blooms, billets or slabs
(4) Hot or cold-working to final shape
(5) Heat-treating.

Properties of Duralumin.—Annealed duralumin can be heat-treated and the maximum physical properties obtained, no matter what the shape or form to which the metal may be reduced. Conversely, heat-treated duralumin can be annealed.

Duralumin can be cold-worked after heat-treatment and aging. This operation produces a hard, smooth finish and materially increases the tensile-strength will increase from 6,000 to 10,000 pounds per square inch over that of the heat-treated metal, but the elongation may drop as low as 3 or 4 per cent.

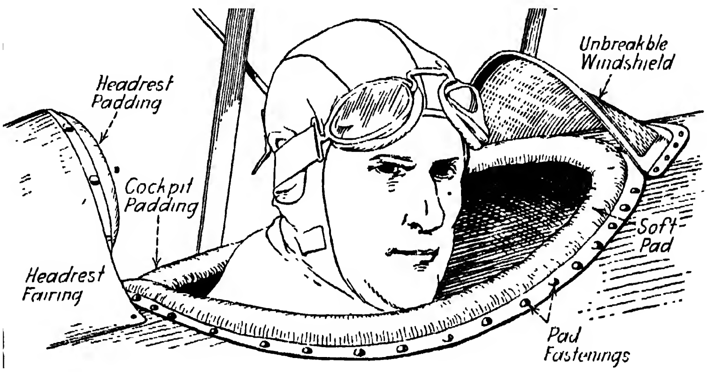


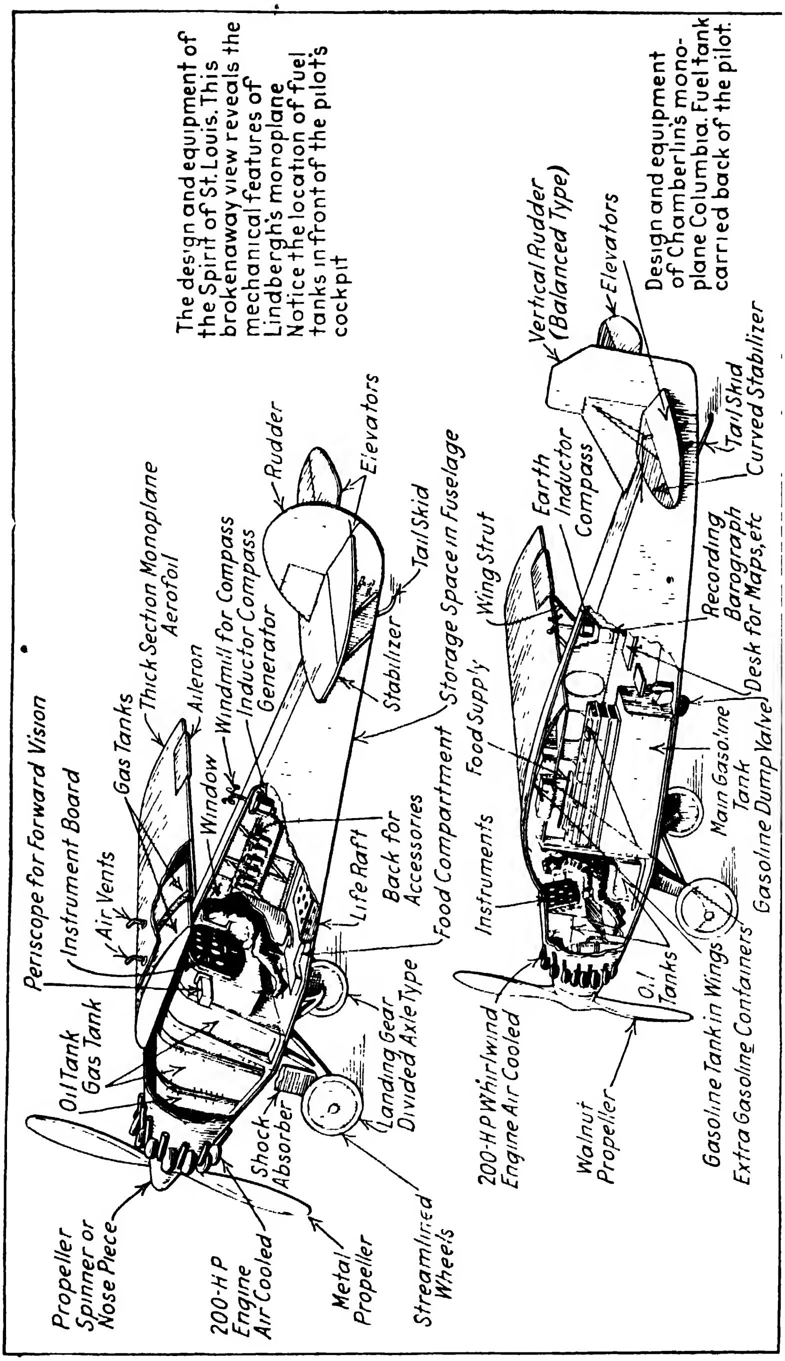
Fig. 91.—Typical Open Cockpit of Airplane Fuselage, Showing Protection Afforded Pilot by Windshield and Padding around Cockpit and on Headrest Fairing Piece.

In the annealed form it can be drawn, spun, stamped or formed into a great variety of shapes, as is the case of brass and mild steel. The physical properties in this state average as follows:

Ultimate Tensile-Strength, lb. per sq. in.,	25,000 to 35,000
Elongation in 2 In., per cent,	10 to 14
Brinell Hardness	54 to 60
Scleroscope Hardness	9 to 12

Duralumin in its heat-treated form can be slightly shaped or formed and can be bent cold to 180 degrees over a mandrel four times the thickness of the sheet. Its remarkable tensile-strength is here combined with its maximum elongation as follows:

Ultimate Tensile-Strength, lb. per sq. in.,	55,000 to 62,000
Yield-Point, lb. per sq. in.,	30,000 to 36,000
Elongation in 2 In., per cent,	18 to 25
Brinell Hardness,	93 to 100
Scleroscope Hardness,	23 to 27



Sectional Views of Monoplanes that have Crossed Atlantic Ocean Showing Internal Arrangement. At Top—Plane Used by Lindbergh. Below it is Shown Bellanca Monoplane Used by Chamberlain and Levine.

Heat-treated duralumin forgings have similar physical properties. Heat-treated and hard-rolled duralumin is used where no bending or forming is required. It is a very hard, strong, springy metal in this state and machines or polishes beautifully. Its physical properties in this form average as follows:

Ultimate Tensile-Strength, lb. per sq. in.,	67,000 to 72,000
Yield-Point, lb. per sq. in.,	55,000 to 65,000
Elongation in 2 In., per cent,	3 to 8
Brinell Hardness,	130 to 140
Scleroscope Hardness,	37 to 42

Preventing Corrosion of Metal.—Corrosion of duralumin has been compared with rusting in steel and must be taken care of by protective coatings. These may be applied by painting or electrolytic treatments. Some insulating material must be interposed between the duralumin surface and the corroding elements. Lionoil, manufactured by Berry Brothers of Detroit, is an anti-rust material produced through treatment at high temperature of a combination of several oils. Its preserving action for all metals is such that a polished iron-plate covered in part with Lionoil and exposed to dampness does not show any alteration in the protected part after being in contact with damp ground or damp air for a long time, whereas, the part not covered with Lionoil becomes entirely rusty. Repeated tests under all forms have given the best results even subject to the action of acids and to that of certain alkaloids.

It is especially in aviation that Lionoil has played an extremely important part. Duralumin may, at the present time, be efficiently protected against the harmful influences of dampness, of sea water, and even of acids.

The first tests carried out at the Naval Establishment of Saint-Raphael, in France have enabled one to appreciate the non-protected samples of duralumin quickly deteriorated, whereas those protected by the ordinary methods resisted longer, and that those treated with Lionoil were absolutely intact. Lionoil is applied with great facility, either with a brush or by means of dipping or spraying processes or any other method according to the importance and possibilities of upkeep of the part to be protected. It flows very easily and covers about 600 square feet of smooth and dry surface per gallon. Once applied, it is transparent, extremely durable and gradually becomes harder and harder, and after drying it may receive any paint whatsoever, to which it imparts great durability. "Lionoil Clear" is said to be used by many of the leading constructors, both for land and sea machines, as the only dope which absolutely protects duralumin and renders both wood and fabric waterproof with a thickness of 1/100 of a millimeter per coat.

Properties of Steel for Fuselage Construction.—Steel is used in many parts of the airplane fuselage and while there has been a wide range of ferrous alloys to choose from, engineers have felt that most useful purposes would be served by concentrating on the use of a relatively small number of alloys. The properties of steel tubing, compared to those of duralumin, as recommended by the S. A. E. are such that practically all needs may be met without radical departure from the strength values given.

The adoption of specific strength values for structural materials filled a long-felt want of the designer and eliminated many points of controversy that have always existed between different schools of metallurgists and designers. These values are summarized below, all values being in pounds per square inch:

Cold Rolled Medium Carbon Steel (SAE 1025)

55,000..............Tensile strength
36,000..............Yield point
90,000..............Bearing strength (except hinges)
60,000..............Bearing strength for hinges and where subjected to stress reversals
55,000..............Compression strength
35,000..............Shearing strength

Heat Treated Duralumin (17ST)

Sheet	Bar	Tubing
55,000	55,000 (¾" diam. and below) 50,000 (above ¾" diam.)	55,000 tensile str.
30,000	30,000 (¾" diam. and below) 25,000 (above ¾" diam.)	30,000 yield point
75,000	75,000	75,000* bearing str.
27,000 (abv. 1/16" thick) 20,000 (bel. 1/16" thick)	30,000	27,000 shearing str.

Chrome Molybdenum Steel Tubing (as received)

95,000................Tensile strength
60,000................Yield point
80,000................Tension near welds
50,000................Shear near welds
60,000................Shear unwelded
125,000................Bearing, near welds
140,000................Bearing, unwelded

Heat Treated Alloy Steels

(Chrome Molybdenum, chrome vanadium, 3½% Nickel S.A.E. 2330)

Ultimate Tension	Yield Point	Bearing Strength	Shearing Strength
100,000	80,000	140,000	65,000
125,000	105,000	175,000	80,000
150,000	125,000	190,000	100,000
180,000	140,000	200,000	115,000

The bearing strength to be reduced to 125,000 near welds.

The steel work of a fuselage, especially fittings, being highly stressed, it is especially necessary to protect it against salt water corrosion when used in seaplanes. The development of the Navy practice may be of interest at this place. At the start of the war aircraft fittings were copper plated and in some instances the copper plating was covered by nickel plating. If the

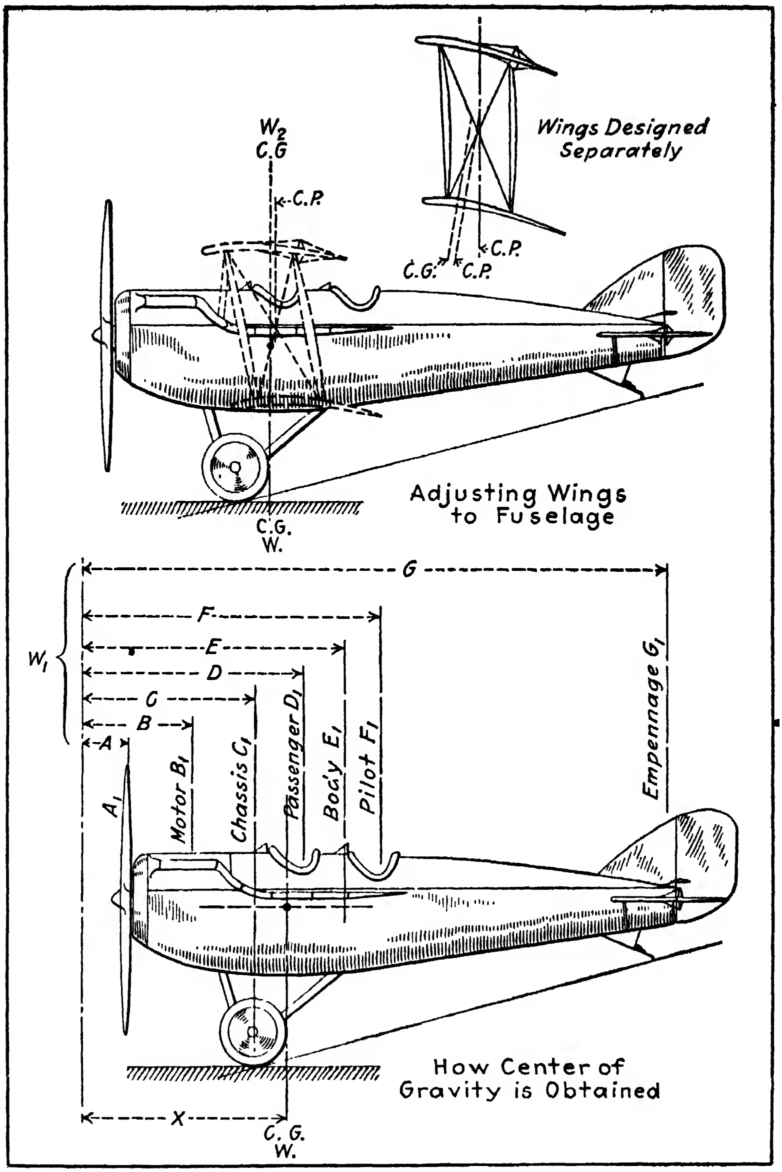


Fig. 92.—Diagrams Showing Simple Method of Weight-Distribution in Airplane Design.

plating became scratched or abraded, moisture and air were admitted and very rapid corrosion would ensue, the iron being electro-positive to the copper or nickel and thus forming a primary battery.

Recognizing the fact that zinc is a metal that is strongly electro-positive to iron it was decided to eliminate copper and nickel plating and to use in place thereof galvanized coatings produced either by the hot dip, electro-galvanizing or sherardizing processes. Metal thus treated, even when abraded, is protected from corrosion because of the strong electro-positive

nature of the zinc, which has a high protective influence upon any adjacent areas of steel that may be uncoated or scratched. Since the hot dip process operates at a high temperature, approximately 375 to 475 degrees centigrade, it might injuriously affect certain types of heat-treated steel alloys and the electro-galvanizing method is used wherever possible and is required for all alloy steels. Corrosive influences are also at work on land planes and proper protection of metal members by surface coatings is equally important.

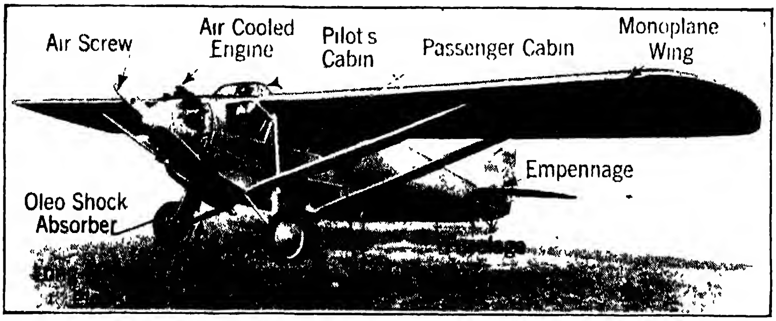


Fig. 93.—Travel Air-Whirlwind Cabin Monoplane Showing Enclosed Cockpit for Pilot, Use of Struts for Monoplane Aerofoil Bracing and Split Axle Landing Gear.

How Coincidence of Centers Is Obtained.—An important point in the design of the airplane fuselage is the proper distribution of weighty parts and location of supporting surfaces to secure a proper coincidence of the important centers of gravity and pressure. The subject is covered in a very able manner by B. Russell Shaw, writing in Aviation and Aeronautical Engineering, who calls attention to some points in airplane design worthy of mention.

A procedure often improperly followed in designing an airplane is the correct balancing of the component parts and giving them the correct relation with the center of pressure.

Some designers draw the complete machine, locate the center of pressure and center of gravity, then give them the correct relation by shifting such weights as the pilot and passenger or the gasoline tank. This method is very poor, inasmuch as it does not allow the body struts and ties to be attached at the proper places. The gasoline tank should be given as nearly neutral position as possible, and not shifted.

The seats should not be moved, for once a proper and comfortable arrangement is reached that arrangement should remain, as any moving from this point may cause cramping in an unnatural position. The body should be laid out complete, taking into consideration the range of vision of the pilot. If he is to be placed in front, as in some European machines, then the gunner in the rear seat must have ample room for action. It is sometimes an advantage to have two seats, one above the other, so that the top one may be folded up allowing him to sit almost on the floor of the body for observation, camera work or bomb dropping through a door in the floor.

The center of gravity of the entire body assembly is found by a very

simple method shown in Fig. 92. The weights of the component parts are multiplied by their respective distances.

$$AA_1 + BB_1 + CC_1 + DD_1 + EE_1 + FF_1 + GG_1 \text{ etc.}, = \frac{W_1}{W}$$

The first distance A is anything desired. W = the total weight of all component parts in the body assembly.

After this is done the wings should be considered. They should be drawn upon a separate sheet and the resulting C.P. and C.G. determined, allowance being made for the extra efficiency of the upper plane affecting the combined location of the C.P.

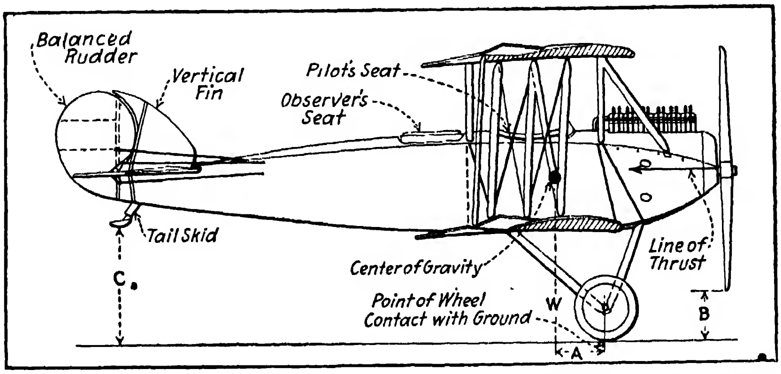


Fig. 94.—The Relative Positions of the Center of Gravity and Point of Wheel Contact with the Ground.

The wings are then placed on the body and shifted until the desired relations of C.P. and C.G. are obtained. This will apply to a neutral tail setting. If a positive or negative tail is used, the forces actuated by it must be taken into account. The resulting forces caused by the leverage between the C.P. or Ky and the C.G. or W, as well as those between the lines of thrust and resistance, must be gone into very carefully when setting the tail plane so that the proper degree of longitudinal stability may be obtained.

Open or Closed Pilot's Cockpit.—Mr. Louis G. Meister, in a paper read before the S. A. E., discusses this subject from the point of view gained by much practical flying under all conditions. He says:

"In the first Air Service transport airplane, the Glenn Martin Transport, the pilot was enclosed in the cabin, but later designs such as the L. W. F., made by the Lewis, Willard, Fowler Co., and the present standard Douglas Transport have the pilot's cockpit open and merely use a windshield for protection. The present Stout all-metal monoplanes used by the Ford air-lines also have the pilot's cockpit open. The preference of the pilots is for the open cockpit, and I believe that the larger commercial airplanes will keep the pilot in the open. The smaller privately owned airplane may prove satisfactory with the enclosed cockpit, provided the visibility is sufficient. The cleanness and the sociability provided by the enclosed cockpit, also the absence of heavy cumbersome flying-

clothes and goggles, are ideal if flying conditions always were ideal; but a fogged windshield might prove disastrous and, in cross-country flying, storms are bound to be encountered. Celluloid or pyralin is easily discolored and is not, in heavy gages, sufficiently transparent for clear vision. Safety-glass panels are strong enough but are exceedingly heavy and have a certain amount of diffraction which troubles a pilot when landing.

The enclosed cabin has an added advantage of comfort in winter flying as it is possible to heat the cabin, although this should not be done by the exhaust-manifolds directly but by the air circulating around the exhaust-manifold and drawn in through stoves. To heat directly by the exhaust gases would constitute too great fire hazard. An enclosed cabin constructed so that the pilot can be partitioned off in stormy weather and can open the window to increase visibility without subjecting the passengers to any discomforts would be the ideal solution of the smaller type privately owned airplane."

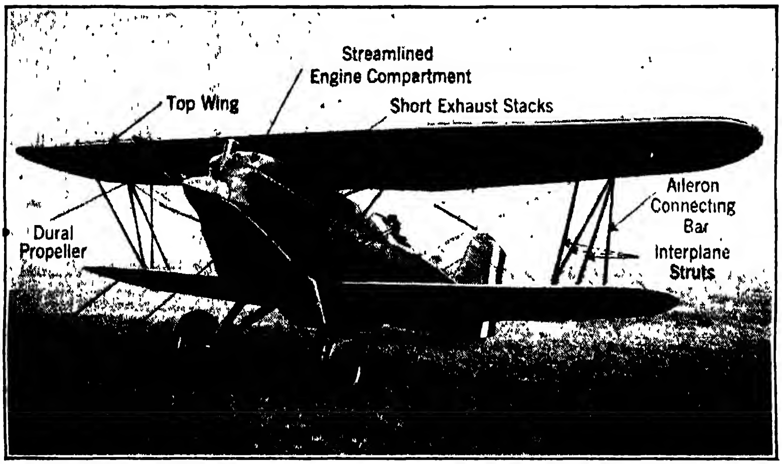


Fig. 95.—Curtiss Hawk Model P I-B, a Modern Biplane Design Having Split Axle Landing Gear. This Airplane is Powered with a Twelve Cylinder V Engine of the Water-cooled Type. Note Location of Radiator at Front below Motor and Effective Streamlining, even to Interplane Struts and Bracing Wires to Reduce Parasitic Resistance.

The illustration at Fig. 93 shows a Travel Air-Whirlwind cabin monoplane with complete enclosure for the pilot and passengers. It also shows an efficient system of monoplane wing bracing and a landing gear of the split axle type.

Landing Gear Forms.—One of the most important problems in connection with airplane design is in the selection of the best type of landing gear. As will be seen by reference to Fig. 94, the important consideration is to provide sufficient ground clearance so that there will be no danger of hitting the ground with a propeller when making a tail high landing. The tread or track must be sufficient so that the machine will be stable when running on the ground. At the same time the tread should not be so great that the machine will be turned around by one wheel striking a soft spot or an

obstruction in the ground when landing. The point of contact of the wheels with the ground must be so arranged in respect to the center of gravity of the machine that there will be no tendency for the machine to nose over when making a moderately tail high landing.

As will be seen at Fig. 94, a line drawn from the center of gravity to the ground when the machine is in its normal flying position should come well back of the point of contact of the landing gear wheels and the ground. This will result in the machine coming to rest with the tail skid on the ground instead of with the tail up in the air and the machine on its nose as will result from carrying the center of gravity or moving the axle so that the line W would coincide with the axle or touch the ground at a

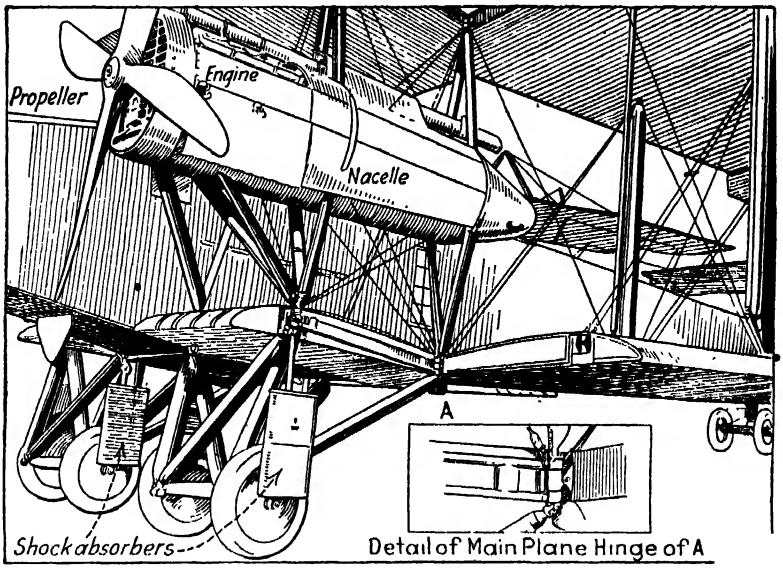


Fig. 96.—Landing Gear of Heavy Bombing Plane Showing Use of Four Wheels, Each Having its Own Shock Absorber to Carry the Load.

point ahead of where the wheel tires rest on the ground. With the ordinary form of rubber shock absorber an axle movement of four to six inches is provided, and this means that under normal conditions when the machine is standing on the ground and the shock absorbers are not extended, the distance should be at least one foot, which will give a clearance of about half that if the shock absorber rubbers are stretched to the limit.

Split Axle Landing Gears.—Landing gears are now almost universally of the split axle type, as shown in Figs. 93 and 95, which makes landings in plowed or furrowed fields safer and allows the plane to pass readily over rocks, stumps and other obstacles which would damage an airplane using a straight axle. The latest shock absorbers are of the rubber-disc type, such as is shown in Fig. 97. They require no maintenance and eliminate the trouble of re-wrapping shock absorbers, which is necessary periodically with the old-type elastic shock absorber cord, but many airplanes are still equipped with cord shock absorbers.

Wheel Tread Depends on Spread.—The ordinary tread or distance between the wheels depends on the size and weight of the machine and the wing spread. Naturally, the greater the spread the wider apart the wheels must be. On machines having a spread in excess of 50 feet it sometimes is the practice to provide two independent landing gears which may be spaced as much as 12 feet apart. This arrangement is clearly shown at Fig. 96, which shows the design used on a large wartime bombing plane. Tires on large planes may be 40 inches in diameter by 10 inches in width and even larger ones have been made. Some early airplanes had the landing gear of the skid form having the skids separated by 10 or 12 feet and having a short axle carrying two wheels which are 16 to 18 inches apart straddling the skid. Distance members are provided so that the wheels will track properly and the usual form of shock absorber cable is wound around the

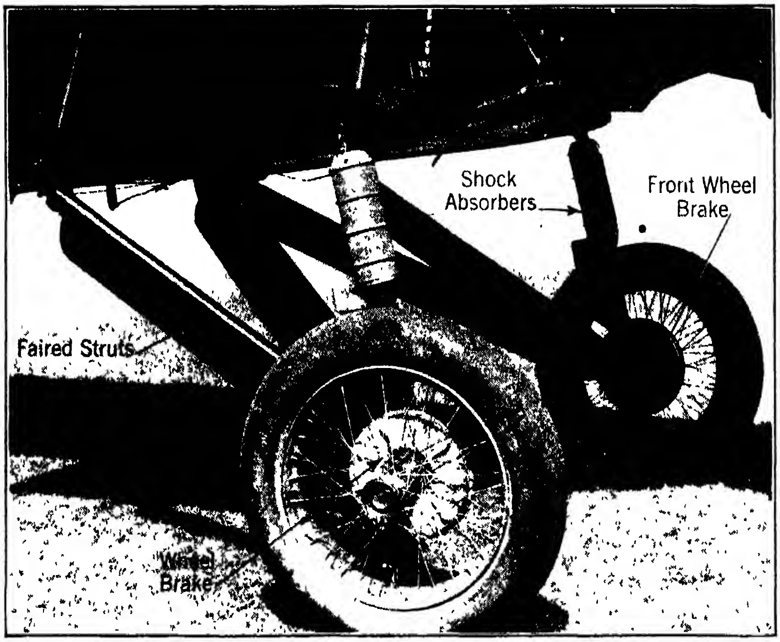


Fig. 97.—Landing Gear of Buhl-Verville Airster Showing Split Axle Feature, Novel Shock Absorbers and Sauzedde Wheel Brakes.

axle and skid. The tread of the average tractor biplane ranging from 40 to 50 feet spread will be about 6 to 8 feet. An empirical figure based on average practice would give a wheel track of about one-seventh the effective wing span though this may be greatly departed from in some instances.

Another factor that regulates the height of the landing gear besides that of propeller clearance is the maximum angle of incidence it is desired to attain or have the wings inclined at when the tail skid is resting on the ground. In order to obtain a short run after the machine lands, it is common practice to make a tail low landing and have the wings at an angle of incidence of 15 or 16 degrees. This, of course, would call for a very short tail skid if the landing gear was ot moderate height or a higher landing gear if a really efficient tail skid was desired.

Brakes for Airplane Wheels.—Quick stopping is also a safety feature, and several of the latest types of commercial airplane are equipped with brakes. These include the Buhl-Verville, the landing gear of which is shown at Fig. 97, the Stinson; the Travel-Air; the Ford three-engine; and the Fokker airplanes. Besides shortening the length of roll when landing, they also aid in taxiing in high winds and eliminate the use of chocks under the wheels while warming up, as well as the hazard incurred in removing the chocks from under a whirling propeller. An airplane equipped with

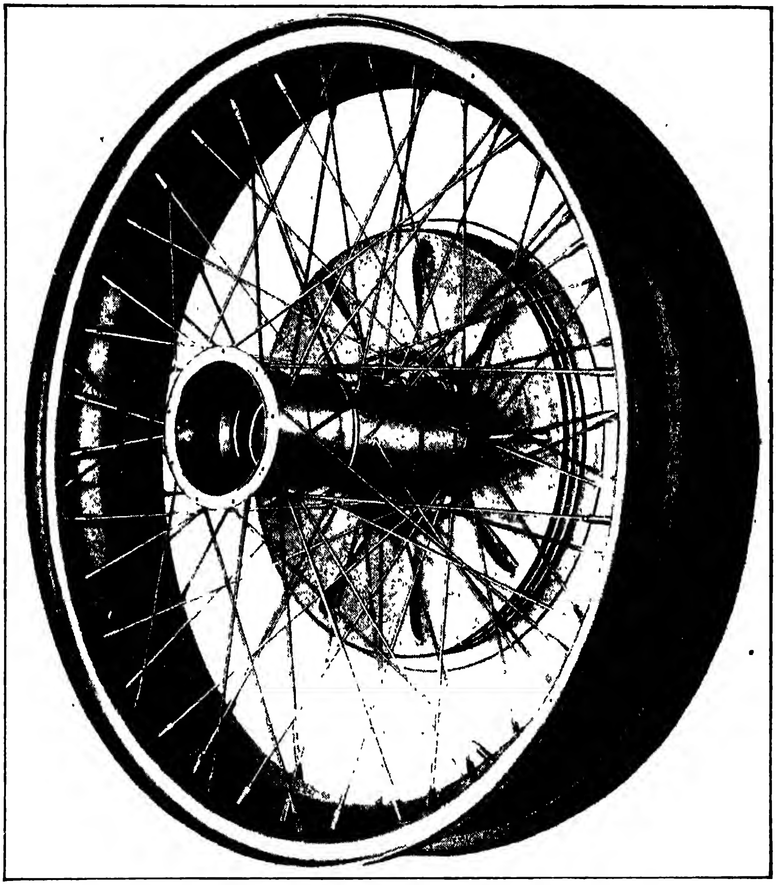


Fig. 98.—Sauzedde Airplane Wheel with Drop Center Rim and Drum for Internal Brake.

brakes is strictly a one-man vehicle. The most modern design of airplane brake is the Sauzedde, manufactured by the Sauzedde Corporation, Detroit. This consists of a wire wheel with three rows of offset spokes, a drop-center rim and the brake-drum streamlined into the wheel as shown at Fig. 98. The entire assembly weighs 6½ pounds more per wheel in the 30 x 5-inch wheel size than it does without brake equipment. The present use of brakes on airplanes is a resurrection of the old French practice which was abandoned in favor of the tail skid brake on account of lightness; but heavy

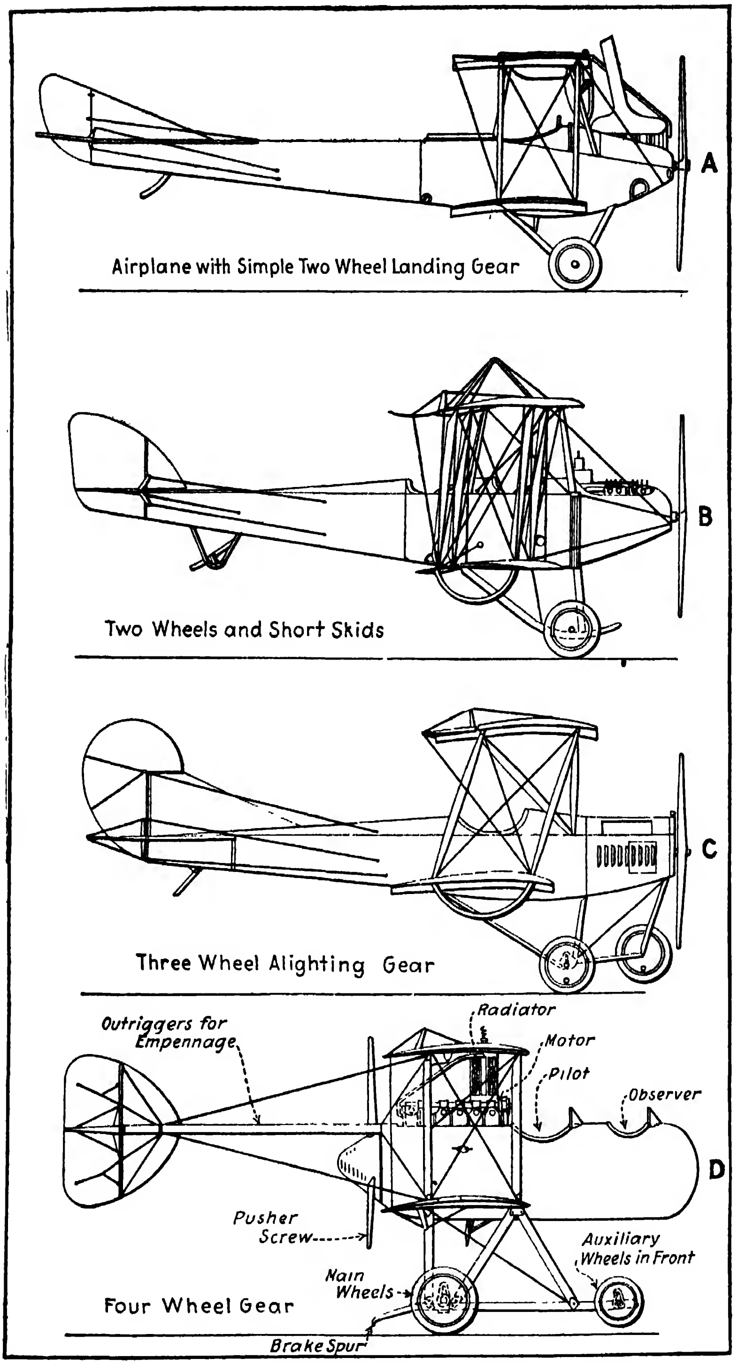


Fig. 99.—Four Types of Landing Gears Showing the Various Designs Employed.

airplanes cut up the airdromes and fields with their tail skids. Modern airplanes eventually will be equipped with a caster-mounted steerable-wheel instead of a tail skid, and an airplane so equipped can readily land on the

fairway of a golf course without plowing any furrows. A wheel will also eliminate the drag of the tail skid and give quicker acceleration in taking-off. The use of brakes may make the present tail skid obsolete.

A number of types of landing gears that have been used are shown at Fig. 99. That at A is a conventional two wheel form, while at B a combined skid and wheel landing gear is shown. To prevent nosing over, on some training machines a three wheel alighting gear was sometimes provided, as shown at Fig. 99 C. The disadvantage of the three wheel landing gear is that it is a more complicated form than the two wheel gear which is so clearly shown and also that it offers more resistance when the machine is in flight. The machine shown at Fig. 99 D was an unconventional machine of the pusher screw type which has four wheels, as indicated. The disadvantage of the three and four wheel types is that the front

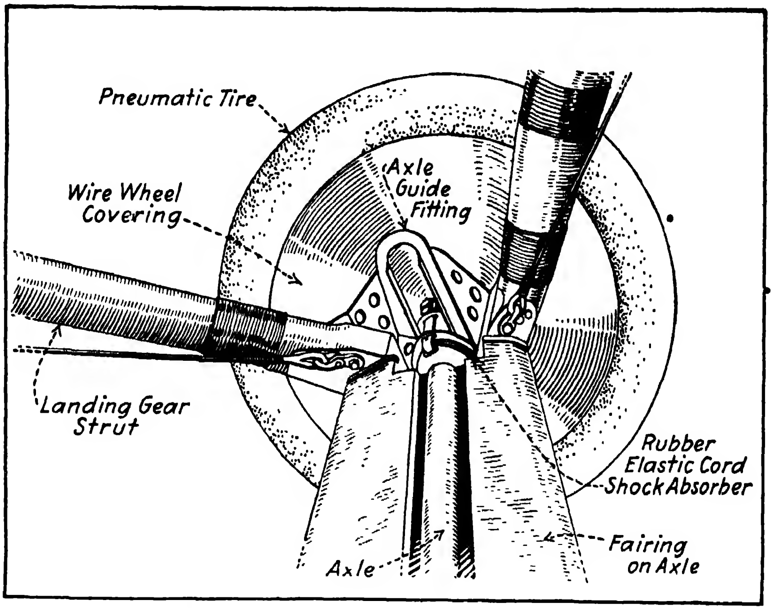


Fig. 100.—Showing Wheel, Axle, and Shock Absorber Parts of Landing Gear Suitable for Medium Weight Airplane.

wheels sometimes take the full force of the landing, and as they are not as large or braced as securely as the main wheels the landing gear may be damaged under landing conditions that would not materially affect a two wheel landing gear.

Airplanes designed to rise from and alight on the water have supporting gears adapted for that medium. The simplest form is the pontoon type which is shown at Fig. 104 A. The form shown at B employs a main float of the single step hydroplane form. The type outlined at Fig. 104 C is known as a flying boat because the supporting wings and control surfaces are attached to what may be considered a regular boat hull.

When an airplane is intended to land and take-off from a flying field or alight on and rise from the water, it is known as an "amphibian." An

example of this combination construction is shown at Fig. 105 which shows the Loening design. As will be apparent from the sketch, the landing wheels are carried clear of the hull and well below it when in use. Mechanism controlled by the pilot makes it possible to withdraw the wheels into spaces made to receive them in the hull and greatly reduce resistance while in flight or when alighting on water.

Balsa Wood Fairing.—Numerous tests have proven conclusively that Balsa wood, a little-known variety in this country, can be employed successfully as fairing on steel tubes, thus releasing a certain amount of spruce for other parts where combined strength and light weight are vital factors. Balsa wood even has some factors of superiority over spruce for fairing.

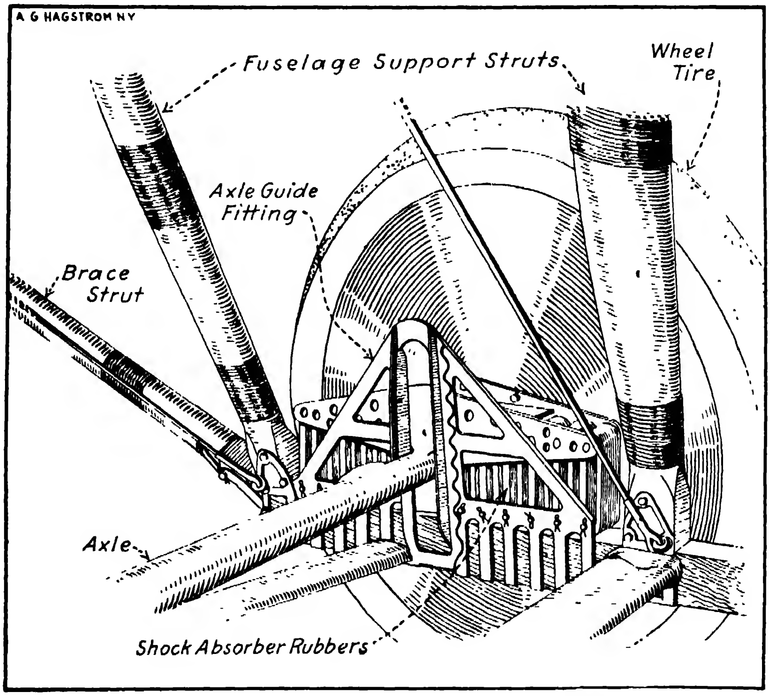


Fig. 101.—Landing Gear Parts for Heavy Machine.

Balsa is a common second-growth tree in Central America and the West Indies, and it also grows well in the Tropics of South America, although not commercially obtainable there at the present time.

While Balsa wood is not as strong as spruce, it nevertheless possesses comparatively great strength. It is much lighter than spruce and can therefore be used in certain places where strength is not a vital factor. Two of its interesting properties are flexibility and great elasticity. Relatively few tests have been made on the mechanical properties of Balsa, but such tests as have been made, indicate an ultimate strength in compression and bending equal to about half of a fair quality of spruce; namely, 2,200 to 2,500 pounds per square inch compression and 2,900 to 3,600 pounds per square inch in bending. Its specific gravity, when free from moisture,

is from .11 to .12 and its weight about 7½ pounds per cubic foot. Owing to the very absorbent nature of the wood, however, its weight usually runs from 8 to 13 pounds per cubic foot.

The extreme lightness of the wood is due to the unusual thinness of its cell walls. As a whole, the structure of balsa resembles that of basswood, poplar and willow, but in its more minute details the structure is unlike that of any other wood. Untreated Balsa wood has a short life and absorbs moisture to such an extent that it is rendered useless for many purposes. In order to determine the best method of treating the wood commercially a number of tests were made with the various schemes for doping and taping the rods with fairing in place, from these tests it was determined that the best method is to treat the completely taped fairing with five coats of dope.

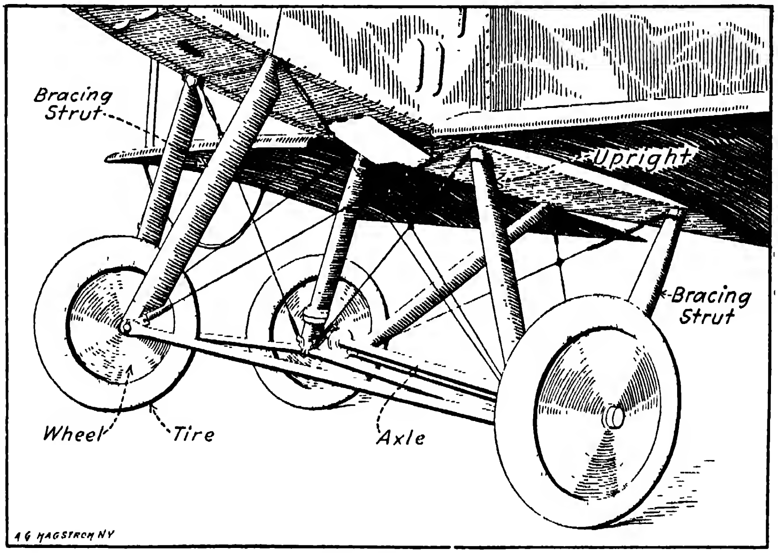


Fig. 102.—Airplane Landing Gear of Three Wheel Type Showing Main Components.

Tests made at McCook Field show conclusively that Balsa wood can be used successfully as fairing on steel tubes; that it can be machined easily, and that it can be treated properly by a simple process easily handled in production. Some slight saving in weight can be affected as against spruce fairing and finally a certain amount of spruce can be released for use in parts where combined strength and light weight are vital factors. An idea of the amount of spruce that can thus be made available, is obtained from the following estimate based upon the requirements of an average machine of the training type. In the manfacture of the interplane and landing gear struts, about 50 board feet of spruce are required. By replacing these parts with steel tubes streamlined with balsa wood, the saving in spruce is equivalent to the amount required to make three wing spars. Thus we see that the use of balsa wood in this connection is well worth the most serious consideration of the designers. Two methods of preparing the fairing are shown in Fig. 106, and Fig. 107. The section may be routed

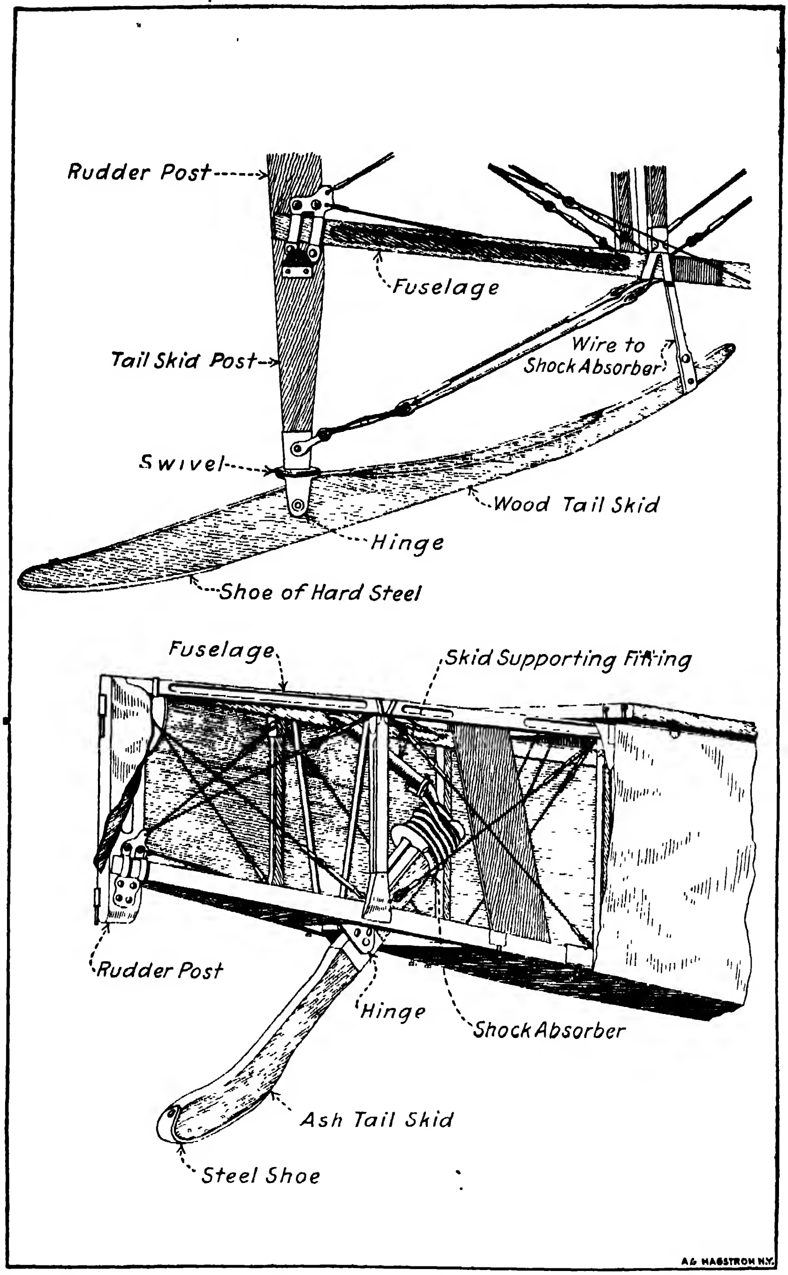


Fig. 103.—Drawings of Typical Airplane Tail Skids, an Important Part of the Landing Gear.

out to secure even greater lightness than with a solid section. The reason for fairing is to give the tubular strut a better streamline shape and faired struts may be used as interplane spacers in biplanes or as monoplane bracing as shown at Fig. 93. Faired tubes are also valuable for landing gears as shown at Figs. 96 and 97.

Woods for Airplane Parts.—Woods used in aeronautical construction work may be divided into two classes, hard woods and soft woods, although in reality many excellent woods are of medium hardness. For the same bulk hard wood is far stronger than most soft woods, besides being more springy and flexible as a rule. For a given weight, however, some of the

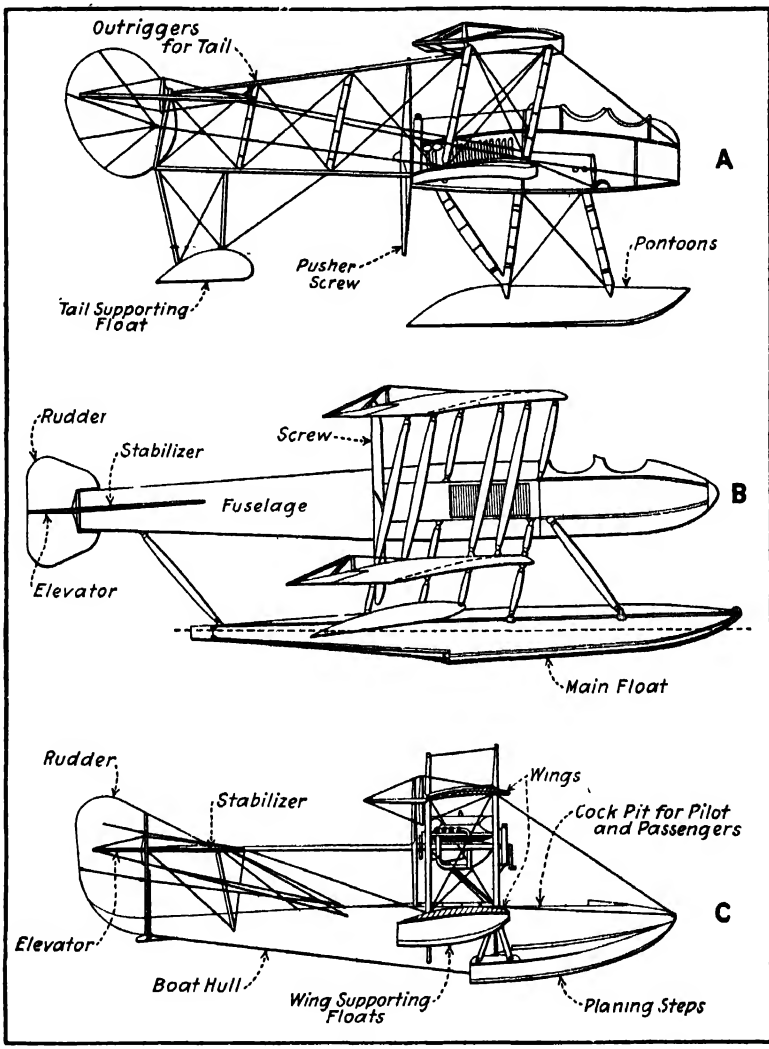


Fig. 104.—The Three Types of Supporting Airplane Floats for Use in the Water. A—Twin Pontoons or Floats. B—Single Float. C—Boat Type Hull.

soft woods are far stronger than the hard woods, while a notable exception to the elastic superiority of hard woods is spruce, which is one of the most flexible and elastic of American woods and that most generally used in modern aircraft. Among the desirable American hard woods may be mentioned:

Apple: A fine timber and with great resistance to splitting. Difficult to secure in large, clear pieces. Excellent for propellers.

Cedar: White cedar is preëminently a superior boat timber and should prove a valuable wood for airplanes as it is light, strong, flexible and free from splitting. *Red cedar* is a strong, very durable wood, but usually very cross grained and full of knots. *Arbor-Vitæ* is a variety of cedar very light and springy, fairly free from splitting and straight-grained. Much used for shingles.

Cypress: Used extensively in boat-building, owing to its durability, strength and freedom from warping, shrinking and swelling. A rather heavy wood and easily split.

Poplar: Very light, porous, soft wood of considerable toughness and strength, but decays rapidly. *Basswood* is sometimes known as "poplar" as is also *Whitewood.* Some varieties weigh as little as 20 pounds to the cubic foot, which is but 5 pounds heavier than cork.

Redwood (California): A beautiful, soft, easily worked wood similar in its properties to *Cypress,* but lighter.

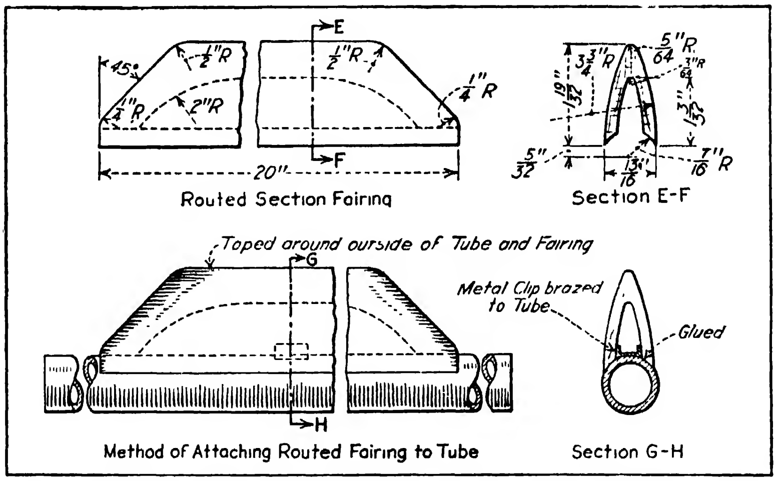


Fig. 107.—How Routed Wood Fairing is Attached to Metal Tubes.

Spruce: The various spruces, especially *Silver* and *California spruce,* are, as far as known, the most satisfactory woods for aeronautical use as they are exceedingly strong for their weight, are very flexible and tough and are probably among the most elastic woods known. Spruce splits easily and the ends where exposed should be tipped with ferrules or wrapped with wire or shellacked thread as splits once started spread rapidly.

Sycamore: A very strong, durable, close-grained wood. Light in weight and exceedingly hard to split. Excellent for short struts, propeller blades, control parts, etc.

Whitewood: Also called *"Tulip Wood,"* is a very fine-grained, soft, durable wood easily worked but brittle and not very strong.

Willow: Exceedingly strong for its weight and very flexible, especially when steamed or water-soaked. It should prove an excellent material for fuselage construction and for propellers.

Metals Used in Airplanes.—Although far less stronger than woods than is generally supposed, yet the various metals greatly exceed most woods in tensile strength and ultimate elasticity. Steels, irons, brass, bronzes, aluminum, monel-metal, etc., are used considerably in aeronautical construction, especially in motors and fuselage fittings, and the following brief descriptions of their compositions and characteristics may be of interest and value.

Steel, especially alloy steel, such as Vanadium, Chrome, Tungsten and Nickel-steels are the strongest metals known, and steel has been produced that showed a tensile strength of over 600,000 pounds per square inch. This was, however, merely experimental steel made in small quantities in the Krupp works and no steel of such strength has ever been produced in commercial quantities.

Gray cast-iron, French iron, Semi-steel and Vanadium-iron are all used extensively for cylinders, pistons, piston rings and other parts where a

TABLE XII

Strength of Various Materials

Woods

Name	Pounds per Cubic Foot	Tensile Strength in Pounds	Compressive Strength in Pounds
Alder	..	.....	6,000– 7,000
Apple	..	.....	.....
Ash	43	11,000	4,600– 8,000
Bamboo	20	.....	.....
Beech	43	8,000 12,000	8,000– 9,000
Birch	35	7,000–10,000	5,000–10,000
California Spruce	..	12,000–14,000	.....
Cedar	35	4,000– 9,500	4,000 - 6,500
Cherry	..	.....	5,000– 6,500
Chestnut	..	7,000–12,000	4,000– 4,800
Elm	36	8,000–13,000	8,000–10,000
Hickory	43	10,000–14,000	8,000– 9,000
Maple	40	8,000–10,000	5,000– 6,000
Oak (live)	67	10,000	8,000–10,000
Oak (white)	43	10,000	5,000– 8,000
Pear	..	7,000–10,000	7,500
Pine (Oregon)	..	9,000–14,000	.....
Pine (Pitch)	..	8,000–10,000	.....
Pine (red)	..	5,000– 8,000	6,000– 7,500
Pine (white)	29	3,000– 7,500	3,000– 6,000
Pine (yellow)	34	5,000–12,000	6,500–10,000
Poplar	24	3,000 - 7,000	5,000– 8,000
Spruce (New Eng.)	31	5,000–10,000	4,500– 6,000
Spruce (Norway)	32	5,000 - 12,500	.....
Spruce (California)	..	12,000–14,000	.....
Sycamore	39	.....	.....
Walnut (black)	..	8,000	5,600– 7,000
Willow	37	10,000	3,000– 6,000

TABLE XII

Strengths of Various Materials—Continued

Metals

Name	Pounds per Cubic Foot	Tensile Strength	Compressive Strength
Aerial metal	98	60,000– 70,000	....
Alumen	184	42,660	....
Aluminum	168	38,393	....
Aluminum bronze	481	92,430	....
Brass	526	85,320– 86,742	....
Chromaluminum	184	63,990	....
Cast iron	444	20,000– 35,000	75,000–150,000
Copper	...	56,880– 58,302	....
Iron (wrought)	482	119,448	....
Magnalium	152	41,238– 63,990	....
Monelmetal	525	87,000–110,000	....
Nickel-aluminum	184	56,880	....
Steel (alloy)	485	125,000–265,000	....
Steel (piano wire)	490	99,540–312,840	....

Name	Miscellaneous Tensile Strength in Pounds
China Grass	22,752
Glue	500– 750
Hemp	6,285–17,000
Horn	9,000
Ivory	16,000
Leather	3,000– 5,000
Rawhide	12,000
Silk	35,000–62,028
Whalebone	7,600

splendid wearing surface and resistance to heat are required without great strength.

Aerial Metal is an alloy of aluminum and lithium of great strength and very light weight, some examples being only one and one-half times as heavy as water.

Alumen: An alloy of 88 per cent aluminum with 10 per cent zinc and 2 per cent copper. One of the strongest aluminum alloys and readily forged and milled but heavier than aluminum or many other similar alloys.

Argentalium is a patented German alloy of aluminum and silver. Its specific gravity is 2.9.

Chromaluminum is another patented German alloy of aluminum, chromium, etc. Its specific gravity is similar to the last and it is the strongest known aluminum alloy.

Duraluminum is commonly known in aeronautical parlance as dural. A full discussion of its properties, composition, etc., has been previously given.

Magnalium: An alloy of aluminum and magnesium, the latter varying from 2 per cent to 12 per cent. Weighs less than pure aluminum and is very strong. It resists corrosion about the same as aluminum and may be easily cast, forged, machined, rolled and drawn.

Wolframium is an aluminum and tungsten alloy with small amounts of copper and zinc. It is patented in Germany and is extensively used in the Zeppelin dirigibles and is somewhat the same as Duraluminum in its general nature.

Bronzes are all those alloys in which copper is combined with other metals to gain strength or other advantages.

Phosphor-bronze is particularly adapted for wire and cable. *Manganese bronze* is nearly as strong as ordinary steel. *Tobin bronze* has a strength equal to steel and is used largely for marine propeller shafts, while *Aluminum bronze* is very tough and elastic, but like all the bronzes is too heavy to be of great value in aviation work.

Monelmetal: A natural alloy of nickel, iron and copper, is as strong as high-grade steel, resists all known causes of corrosion save sulphur fumes and is readily worked, but is very heavy for aerial work. It is, however, an ideal metal for boat uses.

TABLE XIII

Transverse Strengths of Wooden Bars

(Those marked * were supported edgewise; all tests were with bars supported at extreme ends)

Name	Size in Inches	Weight, Ounces	Load Sustained, Pounds
Elm	1 1/4 × 1 1/8 × 12	5¼	900
Elm	1 1/8 × 1 1/8 × 12	4¼	900
Elm	1 1/16 × 1 1/16 × 12	4¼	880
Elm	1 1/16 × 1 1/16 × 12	3⅞	760
Spruce	1 × 1 × 12	4	450
Spruce	1 × 1 × 12	3½	600
Spruce	15/16 × 1 1/8 × 12	3½	390
Spruce	15/16 × 1 1/8 × 12	3	475
*Elm	3/4 × 3/4 × 12	2½	275
*Elm	3/4 × 3/4 × 12	2¼	280
*Spruce	9/16 × 3/16 × 12	2⅛	175
*Spruce	9/16 × 3/16 × 12	2	175

Mass of Material to Construct an Airplane.—There is a surprising amount of material of various kinds necessary to build a single airplane of the more simple kind, and the components of a typical training plane make use of large quantities of some materials and a great variety of materials. The figures given will vary with the airplane design and in this case applies to a composite structure.

Materials involving metals of various kinds include the following:

Nails	4,326
Screws	3,377
Steel Stampings	921
Forgings	798
Turnbuckles	276
Wire	3,262 feet
Aluminum	65 pounds

The various kinds of wooden material mount up as follows:

Spruce	244 feet
Pine	58 feet
Ash	31 feet
Hickory	1½ feet

Other material necessary for the finished plane is as follows:

Veneer	57 square feet
Varnish	11 gallons
Dope	59 gallons
Rubber	34 feet
Linen	201 square yds.

This list of material is exclusive of everything necessary for the engine and if the power plant was considered, there would be much more metal of various kinds than enumerated above.

Standard Definitions

Body Parts

bay—The portion of a face of a truss, or of a fuselage, between adjacent bulkheads or adjacent struts or frame positions.

body—The fuselage or hull, or nacelle (including cowling and covering) nacele mounting.

cockpit—The open spaces in which the pilot and passengers are accommodated. (Fig. 91.) When the cockpit is completely housed in, it is called a cabin. (Fig. 93.)

control stick—The vertical by means of which the longitudinal and lateral controls of an airplane are operated. Pitching is controlled by a fore-and-aft movement of the stick, rolling by a side-to-side movement. (Fig. 90.)

cowling—A removable covering which extends over or around the engine and sometimes over a portion of the fuselage or nacelle as well.

fire wall—A fire-resistance transverse bulkhead, so set as to isolate the engine compartment from the other parts of the structure and thus to reduce the risk from fire in the engine compartment.

fuselage—The structure, of approximately streamline form, to which are attached the wings and tail unit of an airplane. In general it contains the power plant, passengers, cargo, etc. (Figs. 81, 83, 85.)

longeron—A fore-and-aft member of the framing of an airplane fuselage or nacelle, usually continuous across a number of points of support. (Figs. 85 and 89.)

monocoque fuselage—A type of fuselage construction wherein the structure consists of a thin shell of wood, metal, or other material, supported by ribs, frames, belt frames, or bulkheads, but usually without longitudinal members other than the shell itself. The whole is so disposed as to carry the stresses to which the structure is subjected.

nacelle—An inclosed shelter for passengers or for a power plant. A nacelle is usually shorter than a fuselage, and does not carry the tail unit. (Fig. 96.)

rudder—A movable auxiliary airfoil, the function of which is to impress a yawing movement on the aircraft in normal flight. It is usually located at the rear of an aircraft (Fig. 94.)

tail boom—A spar or outrigger connecting the tail surfaces and main supporting surfaces.

Landing Gear Parts

float—A completely inclosed water-tight structure attached to an aircraft in order to give it buoyancy and stability when in contact with the surface of the water. In float seaplanes the crew is carried in a fuselage or nacelle separate from the float. The term "pontoon" is now obsolete. (Fig. 104.)

flotation gear—An emergency gear attached to a landplane to permit alighting on the water and to provide buoyancy when resting on the surface of the water.

hull—The portion of a flying boat which furnishes buoyancy when in contact with the surface of the water. It contains accommodations for the crew and passengers, usually incorporating the functions of a float and fuselage in one unit. (Fig. 104.)

landing gear—The understructure which supports the weight of an aircraft when in contact with the surface of the land or water and reduces the shock on landing. There are five common types—boat type, float type, skid type, wheel type, and ski type. (Amphibian may be a combination of the float or boat type with wheels or skis.)

shock absorber—A device incorporated in the landing gear of an aircraft to reduce the shock imposed on the structure when alighting or taking off. (Figs. 97, 101.) Shock absorbing devices are usually interposed between the main structure and the wheels, floats, skis, or tail skids, to secure resiliency in landing and taxying.

skid—A runner used as a member of the landing gear and designed to aid the aircraft in landing or taxying. (Fig. 99 B.)

tail skid—A skid used to support the tail when in contact with the ground. (Fig. 103.)

wing skid—A skid placed near the wing tip and designed to protect the wing from contact with the ground.

step—A break in the form of the bottom of a float or hull, designed to reduce resistance when under way by rapidly reducing the wetted surfaces as speed increases. It also serves to eliminate suction effects. (Fig. 104.)

Materials and Structure

balloon fabric—The finished material, usually rubberized of which balloon or airship envelopes are made.

biased—Plied fabric in which the threads of the plies are at an angle to each other.

parallel—Plied fabric in which the threads of the plies are parallel to each other.

cloth—Fabric delivered by the bleachery or finisher before it has been proofed, doped, or specially treated for aeronautic use.

dope (airplane)—The liquid material applied to the cloth surfaces of airplanes to increase strength, to produce tautness by shrinking, and to act as a filler for maintaining air-tightness.

dope (airship)—The liquid material applied to rubberized airship fabric to increase gas-tightness. In contrast with airplane dope, it does not cause shrinking.

dope (pigmented)—An aircraft to which a pigment has been added to make an opaque finish, or to protect it from the effects of sunlight.

duralumin—An alloy of aluminum which is much used in aeronautics, especially for the structure of airships and airplanes. Its chemical composition and physical properties are about as follows:

Copper, 3.5 to 4.5 per cent.
Manganese, 0.4 to 1 per cent.
Magnesium, 0.2 to 0.75 per cent.
Aluminum, 92 per cent, minimum.
Tensile strength, ultimate, 55,000 pounds per square inch.
Tensile strength at elastic limit, 30,000 pounds per square inch.
Elongation of 2 inches at ultimate strength (test specimen ½ inch wide), 18 per cent.
Specific gravity not more than 2.85.

fairing—An auxiliary member or structure whose primary function is to reduce head resistance or drag of the part to which it is fitted (without, in general, contributing strength). (Fig. 107.)

fitting—A generic term for any small part used in the structure of an airplane or airship. If without qualification, a metal part is usually understood. It may refer to other parts, such as "fabric fittings." (Fig. 87.)

gas-cell fabric—The fabric used in gas cells of rigid airships, usually goldbeater's-skin fabric, q. v.

goldbeater's fabric—A gas-containing fabric consisting of a layer of light, fine, strong cloth, usually cotton, to which one or more layers of goldbeater's-skins have been cemented. The skins are on the inside and are usually further protected by a coat of fine varnish. Usually used in the gas cells of rigid airships.

laminated wood—A product formed by gluing or otherwise fastening together a number of laminations of wood with the grain substantially parallel. (Differs from plywood in that in the latter the grain of alternate plies is usually crossed at right angles; also, the plies of the latter are usually made up of veneer.)

panel (aerostat)—The unit piece of fabric of which the envelope or outer cover of an aerostat is made. Panels may be assembled into sections, gores, or rings, according to the method of manufacture followed.

In rigid airships the area bounded by two adjacent longitudinals and two adjacent transverses is often referred to as a "panel." This is a structural panel and the expression is borrowed from structural engineers.

plywood—A product formed by gluing together two or more layers of veneer. The alternate plies are usually placed with grain at right angles to the adjacent plies.

proofing—Material incorporated in the fabric of an aerostat at the time of manufacture, to increase its resistance to the weather and/or to prevent the passage of gas (or decrease its permeability).

stay—A wire or other tension member; for example, the stays of the wing and body trussing.

strut—A compression member of a truss frame. For instance, the vertical members of the wing truss of a biplane (interplane struts) and the short vertical and horizontal members separating the longerons (q. v.) in the fuselage. (Fig. 83.)

veneer—Thin sheets of wood, either sliced with a knife or sawed.

wire—In aeronautics, refers specifically to drawn solid wire.

QUESTIONS FOR REVIEW

1. Describe starting or launching system used with early Wright airplanes.
2. How did it differ from the launching system used by Bleriot and Curtiss and what were the advantages of these systems?
3. Name some fundamental airplane design considerations?
4. What is "parasitic resistance" and what steps should be taken to reduce it and why?
5. Describe Wood and wire truss fuselage construction and compare it with plywood structures.
6. How is metal tubing employed in fuselage construction? Give properties of materials used.
7. Describe principal alighting gear forms.
8. Name common woods and metals used in airplane structures.
9. What is a "monocoque" fuselage and what are its advantages?
10. What is a "streamline" body and how is the principle used in aircraft and why?

CHAPTER VII

AIRPLANE POWER PLANT TYPES AND INSTALLATION

Reliability Main Essential—Aerial Motors Must be Light—Air- or Water-Cooled Engines—Relative Engine Weights—Where Air-Cooling is an Advantage—General Requirements from Aircraft Engines—Factors Influencing Power Needed—Airplane Engine Forms—Number of Engines Used—Airplane Engine Installation—Radiator Location Important—Resistance of Radiators—Power Absorbed by Radiators—Table XIV—Characteristics of Typical American Pre-War Aviation Engines—Table XIV, Continued—Data on American Post War Engines—Installing Rotary and Radial Cylinder Engines—Designing Water-Cooled Engines into Aircraft—Air Resistance Characteristics of Engines—Table XV, Resistance of Various Engines at Different Speeds—Value of Inverted Cylinder Engines—Materials Used in Aircraft Engines—Table XVI, Strength-Weight Ratio of Various Metallic Materials—Table XVII, Properties of Aluminum Alloys Used for Aircraft Engine Construction—Airplane Engine Costs.

One of the marked features of aircraft development has been the effect it has had upon the refinement and perfection of the internal combustion motor. Without question, gasoline motors intended for aircraft are the nearest to perfection of any other type yet evolved. Because of the peculiar demands imposed upon the aviation motor, it must possess all the features of reliability, economy and efficiency now present in automobile or marine engines. It must also have distinctive points of its own.

Reliability Main Essential.—Owing to the unstable nature of the medium through which it is operated and the fact that heavier-than-air machines can maintain flight only as long as the power plant is functioning properly, an airship motor must be more reliable than any used on either land or water. While a few pounds of metal, more or less, make practically no difference in a marine motor and have very little effect upon the speed or hill-climbing ability of an automobile, an airship motor must be as light as it is possible to make it because every pound counts, whether the motor is to be fitted into an airplane or into a dirigible balloon.

Aircraft motors, as a rule, must operate constantly at high speeds in order to obtain a maximum power delivery with a minimum piston displacement. In automobiles or motorboats, motors are not required to run constantly at their maximum speed. Most aircraft motors unless they have a large reserve of power, must function for extended periods at speeds as nearly the maximum as possible. Another thing that militates against the aircraft motor is the more or less unsteady foundation to which it is attached. The necessarily light framework of the airplane makes it hard for a motor to perform at maximum efficiency on account of the vibration of its foundation while the craft is in flight. Marine and motor car engines, while not placed on foundations as firm as those provided for stationary power plants, are installed on bases much more stable than the light structure of an airplane. The aircraft motor, therefore, must be balanced to a

nicety and must run steadily under the most unfavorable conditions. Commenting on the subject editorially, "Aviation" says:

"In other classes of gasoline propelled vehicles there are really two types of engine. One, the heavy duty type of engine, which is capable of developing nearly full throttle power for long periods of time, and the other, an engine which will develop a great burst of power but which is not normally expected to be used at full throttle for long periods of time. Most motor boats have heavy duty engines, while most automobiles and motorcycles have reserve power engines which are very reliable at half power but which will break down if run at maximum throttle for long periods of time. Very few stock cars could get through a twenty-four hour race at maximum speed but all of them will run continuously at a normal speed.

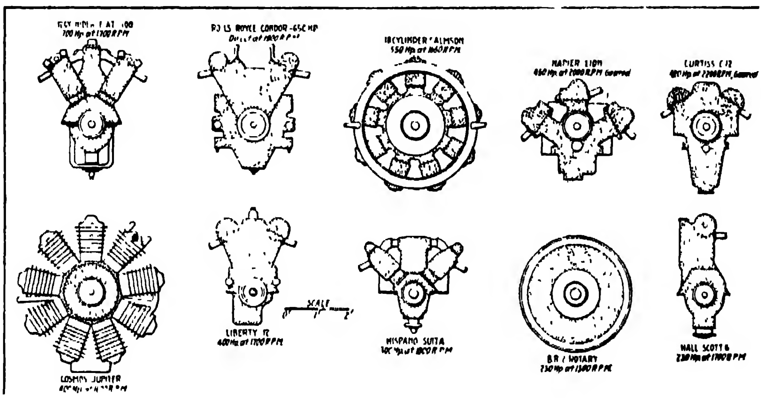


Fig. 108.—Outlines Showing Arrangement of Cylinders of Various Engines that have been Used for Airplane Propulsion.

The airplane is, in most respects, like the motor boat in as far as it is run practically at full throttle so long as the power plant holds out. The Curtiss OX engines are very nearly heavy duty engines. By changing compression, valve action and ignition, almost any good engineer could make these engines develop a lot more power but their power output has been deliberately kept low and they can be run at practically full throttle for long periods of time, with the result that this engine is one of the most popular of aviation engines.

Actually, in one of its essential features, the airplane power plant problem is unlike that of the motor boat for the airplane needs a vast reserve of power with which to take off and climb. Engines can be built to have a great reserve of power for short periods and great endurance at partial throttle for long periods. The real difficulty lies in the pilot. There are few men who can restrain themselves and fly at half throttle even in a plane which has ample reserve power at this speed. There is a constant tendency to speed the engine up to a point where the strains on the metal will ultimately cause crystalization and breakage, whereas, if the engine had been kept throttled, there would have been no over strain on the metal and no tendency to crystalize."

Aerial Motors Must Be Light.—The capacity of light motors designed for aerial work per unit of mass is surprising to those not fully conversant with the possibilities that a thorough knowledge of proportions of parts and the use of special metals developed by the automobile industry make possible. Activity in the development of light motors had been more pronounced in France than in any other country before the war but now the

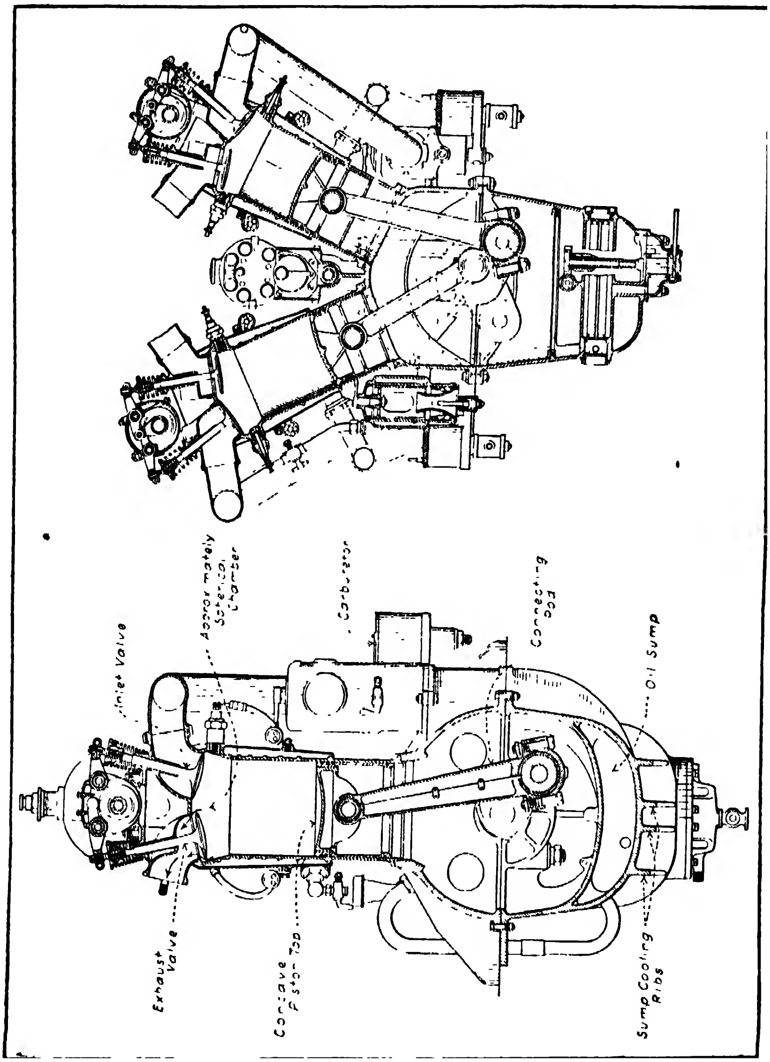


Fig. 109.—Typical Early Aircraft Engines. At Left—Six-Cylinder Vertical Form. At Right—"V" Type with Twelve Cylinders.

product of American designers seems to be supreme. Some of these motors have been very complicated, made light by the skilful proportioning of parts, others are of the refined simpler form, modified from present-day automobile practice. There is a tendency to depart from the freakish or unconventional construction and to adhere more closely to standard forms because it is necessary to have the parts of such size that every quality making for reliability, efficiency and endurance is incorporated in the design. Airplane motors range from two cylinders opposed to forms hav-

ing fourteen, sixteen, eighteen and twenty-four cylinders, and the arrangement of these members varies from the conventional vertical tandem and opposed placing to the V form or the more unusual radial or star motors having either fixed or rotary cylinders. The weight has been reduced so it is possible to obtain a complete power plant of the radial cylinder air-cooled type that will not weigh more than 1.5 pounds per actual horsepower and in some cases less than this figure. Water cooled engines have been developed that will weigh less than 2 pounds per horsepower in the larger horsepowers, figuring dry weight.

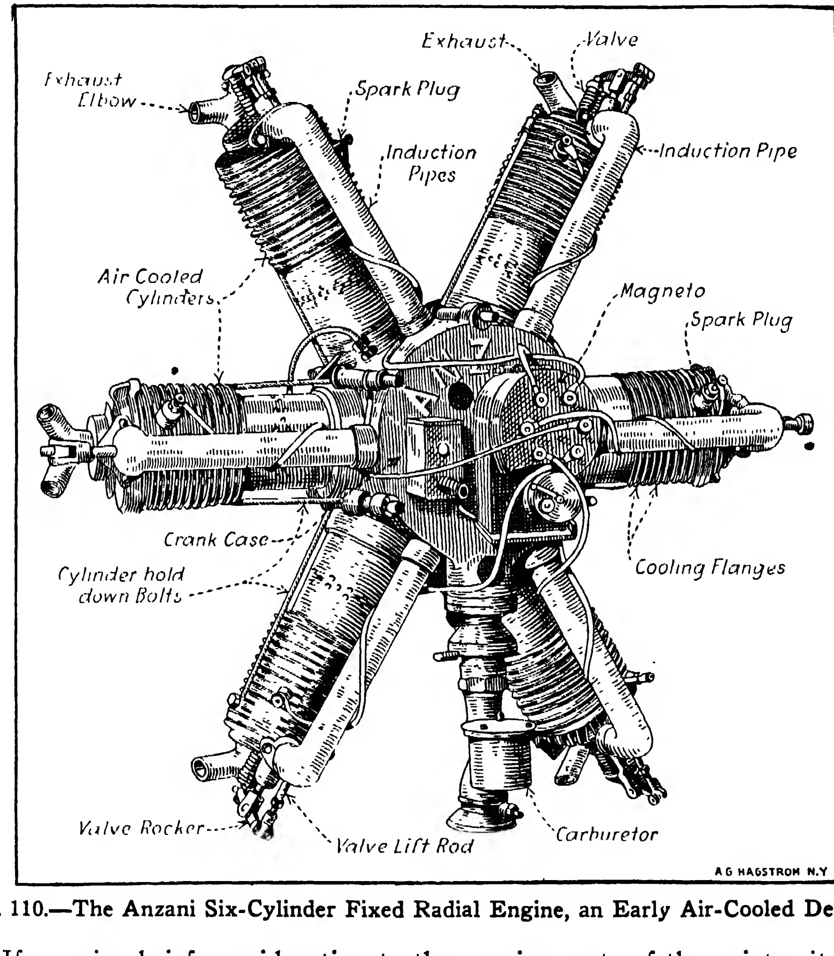


Fig. 110.—The Anzani Six-Cylinder Fixed Radial Engine, an Early Air-Cooled Design.

If we give brief consideration to the requirements of the aviator it will be evident that one of the most important is securing maximum power with minimum mass, and it is desirable to conserve all of the good qualities existing in standard automobile motors. These are certainty of operation, good mechanical balance and uniform delivery of power—fundamental conditions which must be attained before a power plant can be considered practical. There are in addition secondary considerations, none the less desirable, if not absolutely essential. These are minimum consumption of fuel and lubricating oil, which is really a factor of import, for upon the

economy depends the capacity and flying radius. As the amount of liquid fuel must be limited, the most suitable motor will be that which is most powerful and at the same time economical

Another important feature is to secure accessibility of components in order to make easy repair or adjustment of parts possible. It is possible to obtain sufficiently light-weight motors without radical departure from established practice. Water-cooled power plants have been designed that will weigh but 3 pounds per horsepower complete, and in these forms we have a practical power plant capable of extended operation for heavy duty applications.

Fundamentally, success in aircraft operation, whether it be commercial or military, is almost entirely, dependent upon two vital factors: (*a*) dependability and safety, and (*b*) low operating cost per ton-mile of payload carried. Safety and dependability can be had, of course, without low operating cost, but certainly low operating cost cannot be had without safety and dependability. Probably the greatest contributing factor to the present high cost of aircraft operations is the enormous overhead expense incurred by the necessity for frequent and costly repairs and replacements, and by the necessity for constant and most meticulous attention to details. Dependability and reasonable durability must come first and always. With thorough dependability comes safety, and a material reduction in maintenance costs. Next in importance to dependability and durability comes the reduction in aircraft weights, because every pound that can be saved in the structure of the aircraft results in a corresponding increase in the pay-load or in the speed and a decrease in the carrying cost. Generally speaking, any aircraft is only as good as the power plant that sustains and propels it. Any advance in the performance of the aircraft as a whole can proceed but little faster than the advance in the performance of the power plant. The two are inseparable.

Relative Engine Weights.—One often hears the statement that the requirements for commercial aviation are very different from those for military aviation, that for commercial aviation one can afford to use considerably heavier engine types than are at present in common use for military aircraft. A rather careful study of the influence of power plant weight on the amount of pay-load that can be carried throws some interesting light on this subject. Lieutenant Leighton took as the basis for comparison the performance of a type of aircraft that had recently been developed, and that had an unusually high carrying load per horsepower by comparison with existing types of aircraft built at that time.

The total gross weight of the machine as built is 7,175 pounds. The engine used is a standard Liberty developing 400 b. hp., which gives a power loading of 17.9 pound per b. hp., a very satisfactory figure. With a cruising radius of 500 miles this plane as built can carry a pay-load of 1,010 pounds.

The power plant weights, exclusive of fuel, are as follows:

	Lb.
Dry Weight of Liberty Engine	872
Engine Accessories	58
Hand Starting System	17

Propellor	58
Dry Weight of Cooling System	132
Cooling Water	113
Dry Weight of Oil System	33
Dry Weight of Fuel System	184
Engine Controls	15
Total Power Plant Weight	1,462

As a basis of comparison, Lieutenant Leighton took a purely hypothetical assumption that an air-cooled engine that will deliver 400 hp. and that

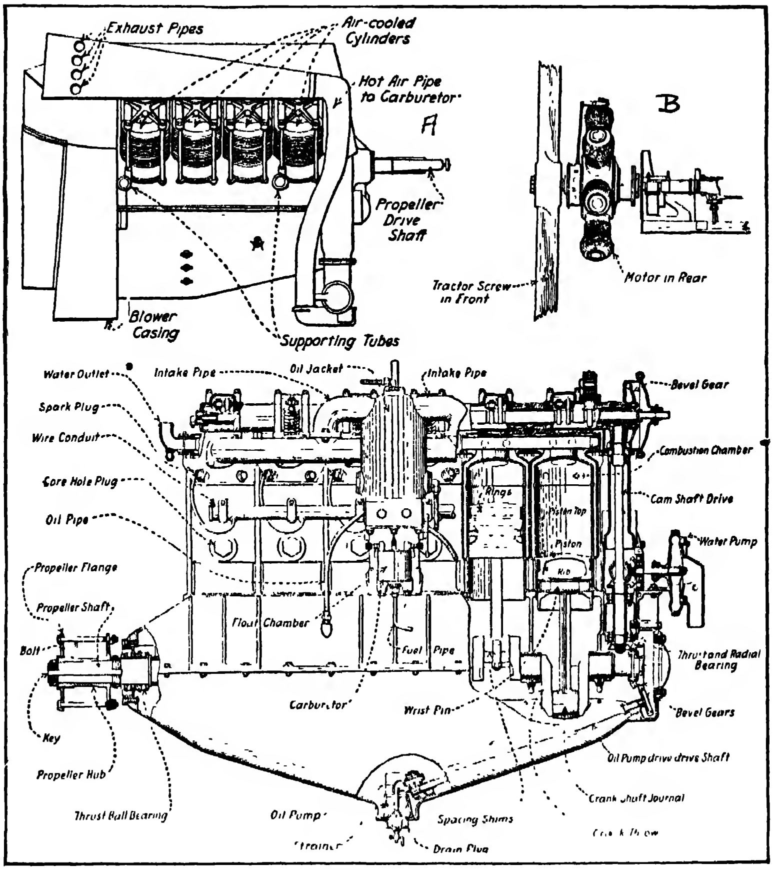


Fig. 110, con't.—Air- and Water-Cooled Aviation Power Plants of the Pre-War Type. A—Renault Eight-Cylinder Air-Cooled. B—Gnome Rotary. At Bottom—Six-Cylinder Type, Water-Cooled Hall-Scott.

will weigh 600 pounds dry is available to replacé the standard Liberty engine and such engines have been developed since he read his paper. With such an engine it is reasonable to assume a power plant weight, exclusive of the fuel which is considered to be the same as in the previous case, of

	Lb.
Engine	600
Engine Accessories	33

Starting System	17
Cooling System	0
Water	0
Dry Weight of Oil System	33
Propeller	58
Dry Weight of Fuel System	184
Engine Controls	15
Total Power Plant Weight	940

Owing to the simpler engine mounting required for the air-cooled engine, there will be an additional saving in the weight that is conservatively estimated at approximately 50 pounds. The total saving in the power plant weight in the case of the latter installation is, therefore

$$1462 - 940 + 50 = 572 \text{ pounds}$$

This saving in the deadweight of the power plant permits an increase of 572 pounds in the pay-load, without in any way affecting the performance characteristics of the airplane.

The Bristol Aeroplane Company of England the manufacturers of the Jupiter air-cooled engine, have been running a convincing endurance reliability test on the engine with the result that the engine has completed the task which it set out to accomplish, namely 25,000 miles. Its actual distance was 25,074 miles—equal to the earth's circumference and a little over, which was accomplished in 225 hours 54 minutes flying time. The engine was sealed, and no replacement of any part was made except that three sets of sparking plugs were used. The flights were made daily between Croydon and Bristol, England. The Jupiter is a radial air-cooled engine with nine cylinders. It has a gasoline consumption of about 22 gallons per hour. It develops, at normal revolutions, 450 hp. for a weight of 1.60 pounds per horsepower.

Lieutenant Hugo Schmidt, U. S. N. also has contributed interesting data to the S. A. E. regarding the experience of the United States Navy with air-cooled engines. He says:

"If one assumes equal durability, flexibility and fuel economy, the air-cooled engine would be more advantageous than the water-cooled type due to the elimination of the weight and the complications imposed by radiators, piping and water. The supposedly large parasite resistance of the radial air-cooled engine is in reality no more than the head-resistance of the radiator and cowling of the water-cooled engine. Streamlining behind an air-cooled engine often can be carried out more advantageously, since the cylinders are the only projections beyond the cowling.

The most annoying source of trouble in water-cooled aircraft-engines is leaky water-jackets during flight. They make the water-cooled cylinder more vulnerable to machine-gun fire When any cylinder goes bad, the flight is ended. This is not necessarily true with air-cooled engines. Recently, a radial air-cooled engine in flight was observed to have one cylinder-head cracked, although the engine was apparently running well. The pilot landed and found that the exhaust-valve retainer on that cylinder had come adrift, allowing the exhaust-valve to drop into the cylinder. He removed the valve-gear from the cracked cylinder and continued his flight,

with remarkably smooth running, on the remaining eight cylinders. This characteristic of air-cooled engines to function in spite of cylinder damage, due to the elimination of elaborate overhead-camshaft gear, is a decided advantage.

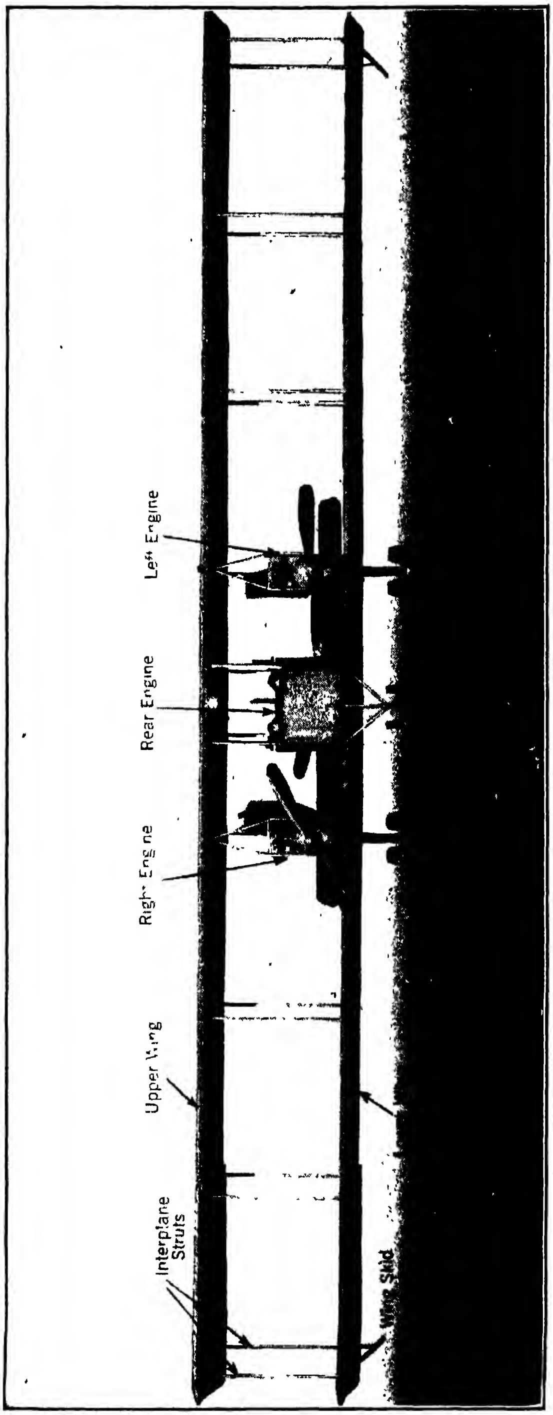


Fig. 111.—Caproni Tri-Motored Bombing Biplane, a Large Wartime Machine. Two Outboard Motors have Tractor Screws, Central Motor Uses a Pusher Screw.

Where Air-Cooling Is an Advantage.—Up to about 450 hp., the radial air-cooled engines developed by the Navy have had a decided advantage in weight per horsepower. It has heretofore been the practice to rate water-cooled engines as regards weight per unit of power on a dry basis, less the radiators, water and piping. Since this is misleading, a better method is to classify them on a basis of pounds per horsepower, ready to fly. The following ratings are on the latter basis. In the 220-hp. class, the Wright J-4 air-cooled engine weighs 2.55 pounds per horsepower and the Wright E-4 water - cooled engine weighs 3.75 pounds per horsepower. This is a total saving of 264 pounds in gross weight for the J-4 engine. In the 350-hp. class, the Wright R-1,200 air-cooled engine weighs approximately 2.4 pounds per horsepower against 3.1 pounds per horsepower for the Curtiss D-12 water-cooled engine and effects a gross saving in weight of about 245 pounds.

Saving in weight diminishes as higher engine-powers are reached.

The 450-hp. Wright P-2 air-cooled engine weighs about 2.3 pounds per horsepower and the 500-hp. Packard 1A-1,500 water-cooled engine weighs 2.4 pounds per horsepower or practically the same weight per horsepower. This reduction in weight per unit of power in the latter case has been accomplished by adopting a higher number of revolutions per minute and the use of reduction gears.

General Requirements of Aircraft Engines.—Definite reasons exist for the choice of air-cooled rather than water-cooled engines but, before explaining these reasons, it is well to state the general requirements of aircraft engines. They must

(1) Be capable of running at full power for long periods and yet have the lowest possible weight per horsepower consistent with reliability and ruggedness.
(2) Have the highest possible dependability and endurance with the lowest possible specific fuel-consumption.
(3) Be flexible and controllable at all speeds from idling to full throttle, on account of the requirements of formation flying and missions calling for varying cruising-speeds.
(4) Be easy to overhaul and to maintain.
(5) Have interchangeability of all parts among engines of the same model.
(6) Have vibration practically eliminated so as to keep down the weight of the engine structure and supports.
(7) Occupy the minimum volume, create the minimum head-resistance and be easy to cowl.
(8) Be as short in length as possible, to concentrate the center of gravity in such a position as to keep the fuselage to maximum shortness in length for maneuverable and structural reasons, and also because short engines are inherently stiffer in the crankcase than longer ones. Short engines are necessarily lighter and more rugged and reduce the multiplicity of engine parts.
(9) Be capable of being built cheaply in quantity production in the shortest time possible.

The specific fuel-consumption of both water-cooled and air-cooled engines is now around 0.5 lb. per b.hp-hr. This factor depends largely upon compression-ratios which are limited by detonating or "pinking" conditions and the necessity for using blended fuels, which are often difficult to obtain. Benzol has been used very successfully but weighs more than gasoline and also tends to solidify in cold weather. The average compression-ratios of the recent engines are in the neighborhood of 5.5 to 1.0.

As early as the begining of 1922, the Navy increased the standard of service acceptability for aircraft engines from a 50-hour test-run to a 300-hour test-run of three 100-hour periods of continuous running at full power on the test-stand. An experienced pilot would never approximate these conditions in flight as he would maintain only enough power to perform his mission and, except for "take-offs," racing and formation flying, rarely would fly at full throttle. On the other hand, an engine in flight often is subjected to sudden altitude and climatic changes. This higher

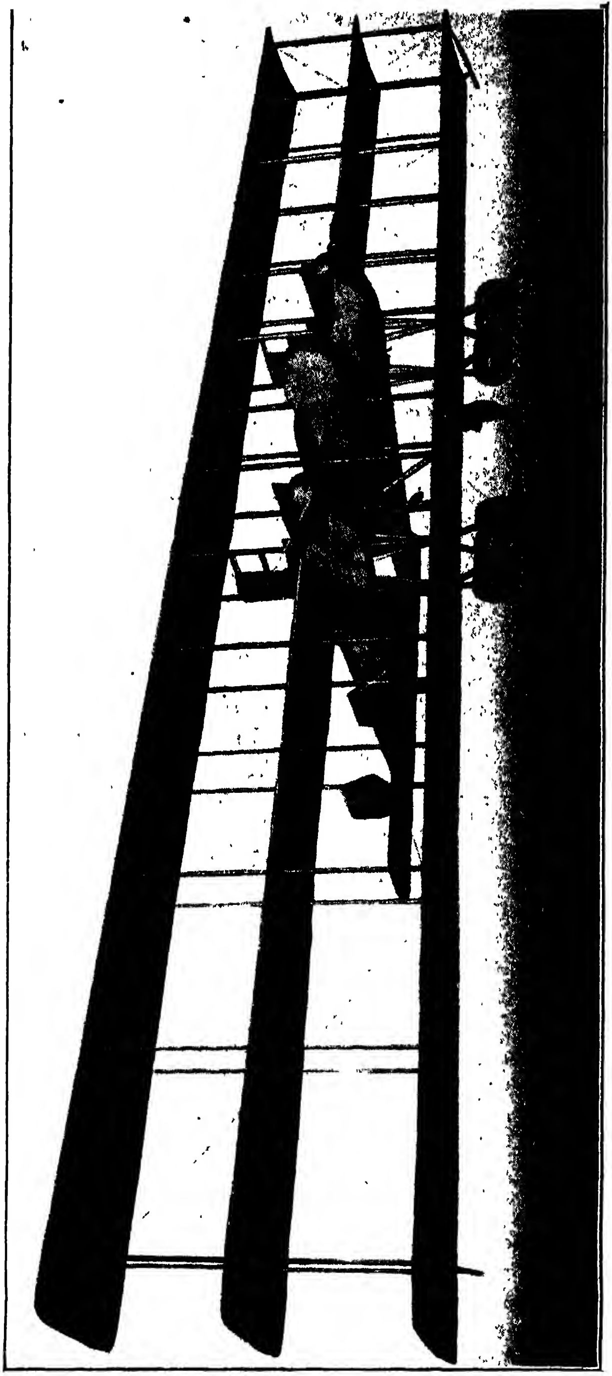


Fig. 112.—Caproni Tri-Motored Bombing Triplane, a Wartime Design of Large Carrying Capacity for Night Bombing. This has the Same Method of Motor Installation as the Biplane. Note Eight Wheeled Landing Gear under Each Outboard Engine.

standard, however, forces both air-cooled and water-cooled engines to greater reliability, ruggedness and endurance.

Comparing the most modern types of engine, we find that the weight per horsepower dry is approximately the same. This, however, is misleading and is a valueless comparison as we are concerned solely with the weight of the power plant ready to fly. Air-cooling eliminates both the troubles and the additional weight attendant upon the water-cooling system. In the matter of mechanical dependability, there seems to be little choice in the engines themselves. The elimination of the water system results in a net gain of 25 to 40 per cent. From the viewpoint of fuel economy, the two types are equally good.

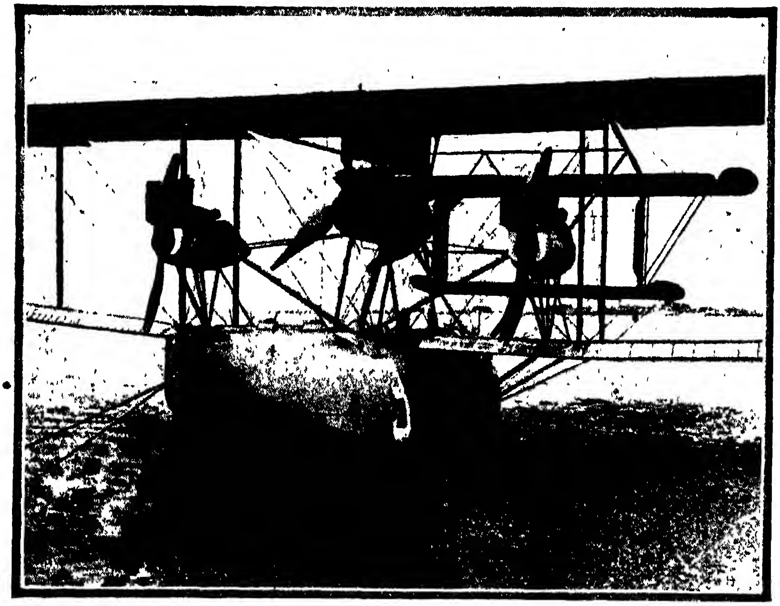


Fig. 112A.—How Four Engines were Placed in the Navy NC Boats.

In the older air-cooled engines, the fuel consumption was definitely inferior to that of the water-cooled engines. Recent changes in cylinder design, which provide for better cooling of the head and a better form for the combustion-chamber, have brought the fuel consumption of the air-cooled engine down to that of the best water-cooled types. The air-cooled engine seems definitely superior to the water-cooled engine viewed from the point of ease of maintenance by completely eliminating radiators, water piping, water-pump, jackets, and a large number and variety of hose connections and glands. In the matters of cost and production, there seems to be little or no choice, but in the latest types it is indicated that the air-cooled engine is outstripping its competitor in these desirable features.

Water-cooling does not lend itself readily to radial construction and in this Country water-cooled engines in general use are all of the V-type. In the air-cooled engines, the radial is the only arrangement which seems to provide uniform cooling. This does not mean that the V-type air-cooled engine cannot be properly cooled. An air-cooled Liberty-12 engine

has been put through extensive flight-tests at McCook Field and satisfactory cooling has been obtained. This engine is fitted with an air-scoop which forces the air into the V and out at the sides between the cylinders. The radial type, however, provides for direct airflow to all cylinders without any change in direction of the normal airflow, and makes possible the ideal cylinder-head, with the head, the valve-seats, and the valve-guides exposed to the maximum airflow.

The in-line engine requires a camshaft enclosure along each bank. The radial type, by having the cylinder-heads arranged in a circle, utilizes the maximum amount of air available from the propeller, while the V-type engine gets the air from a 60-degree sector. It is believed this will be an important feature for ground-test running, for warming-up, and the like, especially in warm climates. The radial engine has the distinct advantages of the short rigid single-throw crankshaft, which eliminates the torsional vibration troubles incident to the longer crankshaft required for the V-type engine. The compactness of the radial engine is very advantageous from the point of view of the airplane designer, as it permits a shorter fuselage and a more concentrated disposition of the principal loads.

Air or Water-Cooled Engines.—Lieutenant B. G. Leighton, U. S. N. in a paper read before the Washington Section of the S. A. E. described some of the developments of aircraft engines used by the Navy.

That the air-cooled engine in the smaller sizes has definitely arrived and has displaced the water-cooled type in all sizes under 300 hp. in the Naval service is the principal conclusion drawn by the author who also makes the predictions that the air-cooled engine will gradually widen its field of usefulness and displace the water-cooled engine entirely and that the chief hope for bettering aircraft engines lies in perfecting the kind of apparatus that engineers have been accustomed to rather than making any radical departures. These conclusions are reached after an exhaustive discussion of the trend of the successive improvements in engines that have increased the safety, the durability, the dependability and the economy of aircraft. The standard of excellence has been raised from the original 50-hour test, which consisted of a series of 5-hour runs, to the present requirement of 300 hours of continuous running with wide-open throttle at sea level that represents approximately 600 hours of normal flying-service and at a speed of 75 m.p.h. would be the equivalent of 45,000 miles of cruising.

This paper was presented several years ago and the experience gained since that time has warranted the following conclusions regarding air-cooled engines which have received a very wide application in airplanes of recent development, both in commercial and military applications.

(1) There is nothing inherent in the air-cooled engine that renders it less durable or dependable as a mechanism than is the water-cooled engine.

(2) As regards thermal characteristics, the air-cooled engine is at least the equal of the water-cooled engine. Block and flight tests over a period of many months have demonstrated a specific power an specific fuel-consumption that is the equal of the best water-cooled engines of comparable power that we know of.

(3) The air-cooled engine is not unduly sensitive to wide changes in the atmospheric temperatures in flight service.
(4) The head-resistance of the radial air-cooled engine of the largest size that we have had in flight, 43-inch diameter overall, is not greater than that of the water-cooled engine of the same power plus the necessary radiator.
(5) The air-cooled engine is much more quickly warmed up and made ready for flight in cold weather than is the water-cooled engine and will withstand long glides and dives at a high altitude without interfering with its operation.
(6) The air-cooled engine requires less attention on the part of the pilot than does the water-cooled engine.
(7) The weight of the air-cooled engine is unquestionably inherently less than that of the best water-cooled engine with its radiator and water.

Operating Principles of Four Cycle Engine.—The reader will notice, in reading the descriptions of engines to follow that practically all aviation engines are valve-in-the head types. Aircraft engines must have maximum efficiency. The type of engine, therefore, that consumes in the highest degree the heat units in each charge of fuel and air, will show the greatest efficiency and economy in service, other things being equal. Of all internal combustion engines this condition is most closely met in the valve-in-head type which has the smallest area of combustion chamber surface and consequently less dissipation of the heat of combustion through the walls. The contrary obtains, however, in that type of engine with the valve pockets in the sides of the combustion chamber common in automobiles thereby necessitating a greater area of combustion chamber surface and consequently a greater percentage of heat wastage. The thermal efficiency of the valve-in-head type is highest, which means that the largest possible amount of energy is developed from a given fuel consumption, and, from the designer's point of view this provides greater economy in operation.

In obtaining perfect combustion two conditions must be provided: The cylinders must be completely cleared of all burned gases before a fresh charge of fuel and air is admitted. Spark plugs must be so located that rapid ignition may be obtained, otherwise slow and therefore wasteful combustion will take place. The location of the valves in the cylinder head and directly over the pistons and the position of the spark plugs in the valve-in-head type of engine meet these two conditions. Important from the standpoint of maintenance will be found the accessibility of the valves and the valve actuating mechanism, a feature which will commend itself to all engaged in minor maintenance operations.

The Four Strokes.—Practically all aircraft engines are four stroke cycle engines. It takes four strokes of the piston or two revolutions of the crank for each explosion or working stroke in each cylinder.

The four strokes as shown at Plate 18 are as follows:

(*a*)—**Suction Stroke.** The intake valve opens and the piston moving down, draws a mixture of gas and air into the cylinder from the carburetor.

(*b*)—**Compression Stroke.** Intake and exhaust valves closed, the pis-

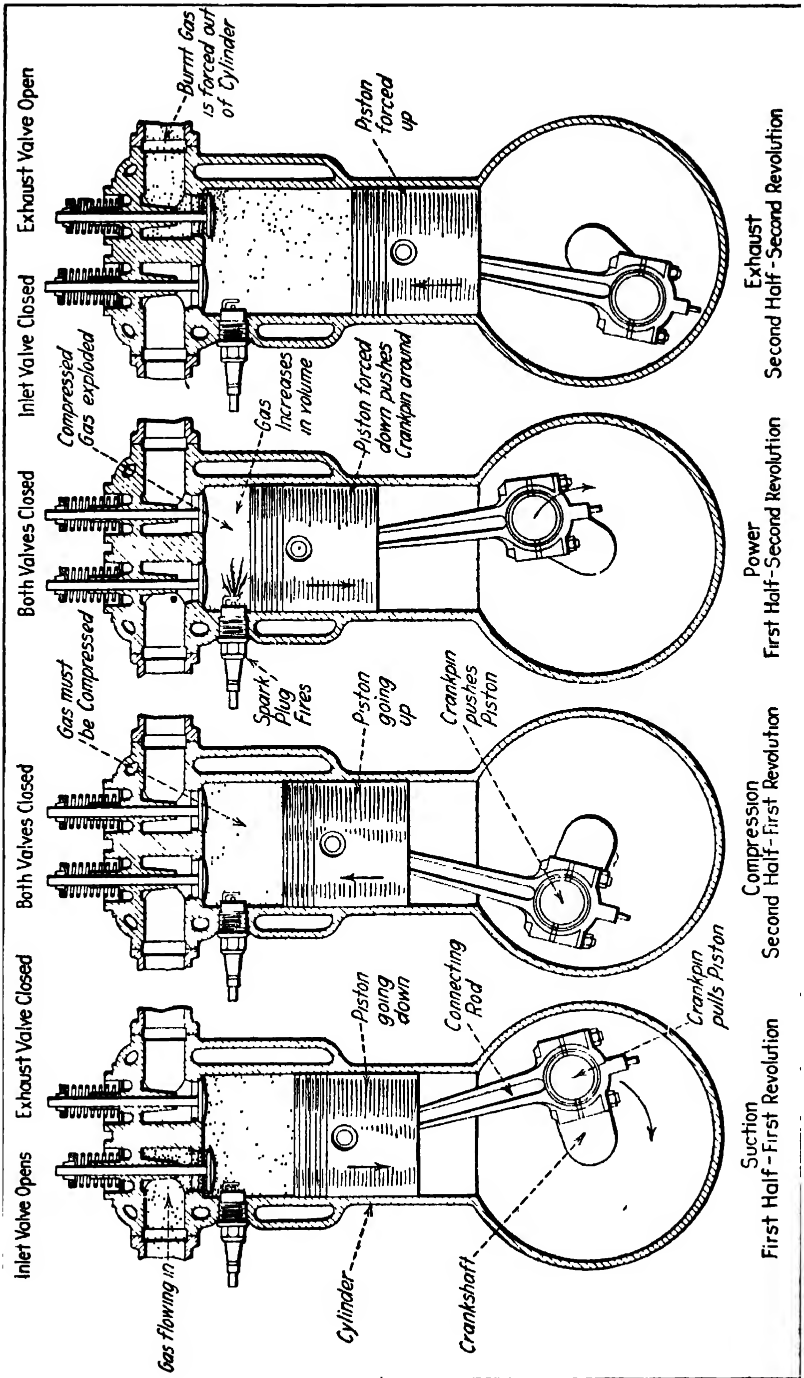


Plate 18.—Diagrams Explaining Action of Four-Cycle Valve-in-the-Head Engine. A System of Construction Most Aircraft Engines Follow.

ton moving up compresses the mixture of gas and air into a highly combustible condition.

(*c*)—**Power Stroke.** When the piston has reached the top of the stroke the spark plug fires and causes an explosion of the compressed gas mixture, forcing the piston down to supply the power.

(*d*)—**Exhaust Stroke.** The intake valve remains closed and the exhaust valve now opens, allowing the dead gas to be forced out on the upward stroke of the piston and clearing the cylinder for the next charge.

There is but one power stroke out of the four in each cylinder the other three preparing for the power stroke. In an engine with six cylinders the crankshaft actually receives only three impulses every revolution. Eight cylinders will give four explosions each revolution, twelve cylinders will produce six impulses each revolution, eighteen cylinders will give nine impulses each turn of the crankshaft. The reason for using multiple cylinder engines in aircraft will be apparent to all.

Factors Influencing Power Needed.—Work is performed whenever an object is moved against a resistance, and the amount of work performed depends not only on the amount of resistance overcome, but also upon the amount of time utilized in accomplishing a given task. Work is measured in horsepower for convenience. It will take one horsepower to move 33,000 pounds 1 foot in one minute or 550 pounds 1 foot in one second. The same work would be done if 330 pounds were moved 100 feet in one minute. It requires a definite amount of power to move an automobile over tke ground at a certain speed, so it must take power to overcome resistance of an airplane in the air. Disregarding the factor of air density, it will take more power as the speed increases if the weight or resistance remains constant, or more power if the speed remains constant and the resistance increases.

The airplane is supported by air reaction under the planes or lifting surfaces and the value of this reaction depends upon the shape of the aerofoil, the amount it is tilted and the speed at which it is drawn through the air. The angle of incidence or degree of wing tilt regulates the power required to a certain degree as this affects the speed of horizontal flight as well as the resistance. Resistance as we have previously considered may be of two kinds, one that is necessary and the other that it is desirable to reduce to the lowest point possible. There is the wing resistance and the sum of resistances of the rest of the machine such as fuselage, struts, wires, landing gear, etc. If we assume that a certain airplane offered a total resistance of 300 pounds and we wished to drive it through the air at a speed of 60 miles per hour, we can find the horsepower needed by a very simple computation as follows:

$$\frac{\text{The product of: 300 pounds resistance times speed of 88 feet per second times 60 seconds in a minute}}{\text{divided by 33,000 foot-pounds per minute in one horsepower}} = \text{H.P. needed}$$

The result is the horsepower needed, or

$$\frac{300 \times 88 \times 60}{33{,}000} = 48 \text{ H.P.}$$

Just as it takes more power to climb a hill than it does to run a car on the level, it takes more power to climb in the air with an airplane than it does to fly on the level. The more rapid the climb, the more power it will take. Naturally the resistance is greater when climbing. If the resistance remains 300 pounds and it is necessary to drive the plane at 90 miles per hour, we merely substitute proper values in the above formula and we have

$$\frac{\text{300 pounds times 132 feet per second times 60 seconds in a minute}}{\text{33,000 foot-pounds per minute in one horsepower}} = 72 \text{ H.P.}$$

The same results can be obtained by dividing the product of the resistance in pounds times speed in feet per second by 550, which is the foot-pounds of work done in one second to equal one horsepower. Naturally, the amount of propeller thrust measured in pounds necessary to drive an airplane must be greater than the resistance by a substantial margin if the plane is to fly and climb as well.

Besides the limitations placed on the size and weight of aircraft another limitation, the lift-drag ratio of the airfoils, must be kept in mind constantly. In any given airplane this ratio determines how much lift is available for useful load after the weight of the complete airplane has been provided for. When choosing a power plant, the two most important values are the pounds per horsepower and the horsepower times the specific fuel-consumption. Every pound which can be saved in the power plant permits not 1 but 3 pounds to be added to the useful load, because 1 pound can be taken from the structure necessary to carry the pound saved and another pound comes out of the wing structure necessary to support the 2 pounds so saved. This saving in weight and size will then reduce the power required to propel the airplane, which result is directly convertible into increased performance, greater range or a still further reduction in weight due to the reduction in fuel carried, tankage, and the like. Any decrease in the specific fuel-consumption effects a similar improvement in the entire airplane. This is of greatest value in long-range aircraft, in view of the fact that modern engines burn their weight in fuel in 3 to 5 hours. It is generally accepted that, due to the savings in weight, size and fuel-consumption made possible by the use of air-cooled engines, any given duty can be done with 75 per cent of the power that would be required with a water-cooled power plant. Air-cooled engines were the first to propel an airplane over the North Pole, the first to stay in the air in an airplane for over 5 hours without refueling and the first to fly over the English Channel, a feat that was accomplished nearly twenty years ago. The most recent and spectacular record made by an air-cooled engine was the propulsion of the Ryan monoplane driven by Captain Charles Lindbergh from New York to Paris in one "hop" lasting over 33 hours, during which time 3,800 miles were covered without a stop by a Wright 220 horsepower nine cylinder radial engine.

Airplane Engine Forms.—Inasmuch as numerous forms of airplane engines have been devised, it would require a volume of considerable size to

describe even the most important developments of recent years. A relatively brief review of the features of some of the most successful airplane motors should suffice to give the reader a complete enough understanding of the art so all types of engines can be readily recognized and the advantages and disadvantages of each type understood.

Aviation engines can be divided into three main classes. One of the earliest attempts to devise distinctive power plant designs for aircraft involved the construction of engines utilizing a radial arrangement of the cylinders or a star-wise disposition. Among the engines of this class may be mentioned the Anzani, in its various forms. These are air-cooled. Engines of this type have been built in cylinder numbers ranging from three to twenty. While the simple forms were popular in the early days of aviation engine development, they have been succeeded by the more conventional ararngements which now form the largest class. A wide variety of engine forms built for airplane use are shown in outline in the illustration at Fig. 109, reproduced from the S. A. E. Journal. The reason for the adoption of a star-wise arrangement of cylinders, shown at Fig. 110, has been previously considered. Smoothness of running can only be obtained by using a considerable number of cylinders. The fundamental reason for the adoption of the star-wise disposition is that a better distribution of stress is obtained by having all of the pistons acting on the same crank-pin so that the crank-throw and pin are continuously under maximum stress. Some difficulty has been experienced in lubricating the lower cylinders in some forms of six-cylinder, rotary crank, radial engines, but these have been largely overcome so they are not as serious in practice as a theoretical consideration would indicate. Very efficient nine cylinder air-cooled radial engines are now built by the Wright Aeronautical Corporation, known as the Whirlwind, and smaller two and three cylinder forms are also built by this firm. Pratt and Whitney Aircraft Company also build successful radial engines as do the Curtiss Company.

Another class of engines developed to meet aviation requirements is a complete departure from the preceding class, though when the engines are at rest it is difficult to differentiate between them. This class includes engines having a star-wise disposition of the cylinders but the cylinders themselves and the crankcase rotate and the crankshaft remains stationary. The important rotary engines are the Gnome, the Le Rhone and the Clerget. By far the most important classification is that including engines which retain the approved design of the types of power plants that have been so widely utilized in automobiles and which have but slight modifications to increase reliability and mechanical strength and produce a reduction in weight. This class includes the vertical engines; the Mercedes, Benz, and Hall-Scott six-cylinder vertical engines and the numerous eight- and twelve-cylinder "V" designs such as the Curtiss, Renault and Liberty.

Number of Engines Used.—The increase in size of modern aircraft has called for a different consideration of the power plant problem than obtained in the past when plane sizes were limited and one engine sufficed to do the work. One important factor that the airplane designer, and even the airship designer must consider is the number of engines he will use to

obtain the power required. A very interesting discussion of this subject appeared in the Engineer, a London publication and it is reproduced in part because it goes into the matter from a historical point of view as well as considering latest practice.

At the outbreak of the war, the idea of constructing planes to be driven by two engines had been broached and discussed, detailed designs had been made for such machines and their power plant equipment, experiments had been conducted, and several multiple-engined airplanes had been constructed. Nevertheless, it was not until June, 1915, that information was received of the definite appearance at the front of a twin-engined German airplane. Although the Germans were thus, apparently, the first to employ such a machine for active military service, they were probably anticipated as regards actual construction by the French twin-engined Cadron biplane and the British twin-engined Dyott machine. The last-named, it is interesting to note, was actually designed before the war and in many respects anticipated the design of the German Gothas of 1917. It was built in 1915, and subsequently flew successfully, although it failed to receive official approval.

The three-engined airplane had also received some attention when the war broke out, notably so from the Italian Caproni, who, in 1914, built and flew a biplane equipped with two 80-hp. tractor engines and a 90-hp. pusher engine. Subsequently, in 1915, the same designer built a successful biplane fitted with three 150-hp. engines and later built large triplanes with three engines. A Caproni three-engine biplane is shown at Fig. 111 and a three-engine triplane at Fig. 112. As the war progressed and the demand arose for heavy bombing machines, the twin-engined airplane took a permanent place in the aeronautical services of all the belligerents. Of these, the Gotha with two 260-hp. engines and the Handley-Page with two 350-hp. units may be taken as typical.

Toward the end of the war the four-engined machine had definitely appeared, and was being built in considerable numbers, in England, at least, while a five-engined German machine was brought down in France in August, 1918. Since the armistice was signed, the four-engined machine has become quite familiar, and the development of the five-engined design has progressed to the extent that there is now in existence a large British seaplane equipped with five Rolls-Royce engines which has flown successfully. Reports indicate that airplanes with eight engines are to be built in England and ten-engine seaplanes of very large dimensions are projected in Germany.

The airplane power plant problem at the present moment is a peculiarly complicated one, and in no respect is its complexity greater than in multiple-engined machines. A very strong reason for fitting an airplane with more than one engine, at least so far as civilian flying is concerned, is, of course, the increased safety insured by so doing. With a twin-engined machine the chances of both failing before a safe landing can be effected are now very small. During the war, it may be said by way of illustrating this remark, a Handley-Page bomber as a result of a direct hit had its lower wings reduced to shreds and tatters and one of its engines put out of action; yet this machine flew back 60 miles to its airdrome, and

lighted there safely. With a three-engined machine, it may be taken that all chances of having to make a forced landing as a result of engine trouble developing are eliminated. A four-engined airplane possesses the same characteristic, and with something over. Indeed, it can be asserted that as regards the avoidance of forced descents the four-engined machine possesses a factor of safety which is, or should be, satisfactory to all concerned. To increase the number of engines above four on the grounds of safety is clearly superogatory.

Setting aside such cases, if there be any, in which the multiplicity of engines is dictated by a desire to utilize existing stocks left over from the war program, it might be suggested that several small units are preferred to one or two larger units because the design and production of the former have been brought to a considerable degree of perfection, whereas the large aircraft engine possessing an equal trustworthiness has yet to be built. So far as air-cooled engines are concerned, it may be true that large units are not installed because large units are not yet available. On the other hand, the largest size at present made, we have recently seen an air-cooled engine developing 500 b. hp., is sufficient to effect a reduction of some 25 per cent in the number of engines fitted on the four-engined Handley-Page machine.

Water-cooled engines of 500 hp., such as the eighteen-cylinder, three-row Sunbeam, have been manufactured in England for some time, while single engines of 1,000 hp. are within reach of present-day production. In support of the latter assertion, it may be said that a twelve-cylinder Liberty engine has, under special conditions, developed 526 hp., and that a twenty-four-cylinder engine of the same design has been made recently and tested with satisfactory results though it did not produce twice the power of a twelve-cylinder.

It seems clear, then, that the tendency to multiply the engine units on an airplane cannot be set down wholly to a deficiency of large powered engines. The true reason, or a large part of it, for adopting a multiplicity of engines lies, in fact, not with the aircraft engine builder, but with the makers of the airplane itself and of its propellers. The eight-engined seaplane referred to will probably have a horsepower of nearly 3,000. Even were a thoroughly trustworthy 1,000-hp. aeronautic engine available, it is doubtful if in the present state of the aircraft building art the designers would have chosen to do other than employ eight small engines rather than three large; for by splitting up the power between a number of units, they effect a corresponding distribution of the flying stresses in the structural parts of the machine. Further, it can be asserted that the airplane propeller capable of using 1,000 hp. on a scale of efficiency comparable with that manifested by smaller existing propellers has yet to be designed and made. It is to be noted that, as with the marine propeller, the higher the engine speed the more difficult is it to provide a propeller which will utilize the available power efficiently, and that aeronautic engine builders are already sacrificing something to meet the short-comings of the propeller by fitting reduction gearing on their higher speed engines. Thus the Rolls-Royce, Sunbeam, Hispano and Cosmos engines, all of which run at or over 2,000 r.p.m., are forced to employ reduction gearing, of approximately a

5 to 3 ratio, because of the present impossibility of obtaining propellers capable of utilizing the full speed economically.

At the present stage of development, the weight per horsepower of an engine does not actually vary in proportion with the power. That is to say, present day low powered engines weigh per horsepower, more than the larger engines. The effect of this upon modern design will be that a plane requiring a given power, if it is to incorporate the three-engine principle, will have a smaller amount of pay-load carrying capacity than a similar single engine plane of equal horsepower, though this deficiency will probably not be very great. Aerodynamical considerations favor a single engine because it is obvious that it will offer less parasitic resistance than three independent engines. On the other hand, the almost complete freedom from forced landings will be very important to air transport and, in fact, to all forms of aerial service. It seems safe to predict, therefore, that the three-engine airplane will be an absolute necessity to the successful operation of a passenger carrying air transport project. In such a case a passenger airliner will be equipped with three small engines preferably air-cooled together totaling the required maximum horsepower necessary for taking off and climbing, or in making headway against the highest head-winds which might be met with. Under normal conditions the plane would be flown on two-thirds or three-quarters throttle for all engines, just as in a single engine plane, but in the event of failure of any one engine, the power of the other two at full throttle will be sufficient to maintain level flight until the plane reaches its destination.

The parasitic resistance that obtains when three radial cylinder air-cooled engines are used for power can be greatly reduced by properly streamlining the engine supports, especially those of the outboard engines as properly housing the engine mounted in the fuselage offers no particular difficulty. The outboard engines of the Fokker airplane are carried below the monoplane wing structure as shown at Fig. 113. The engine is almost entirely enclosed in a metal cowling and only the cylinder heads and upper portion of the cylinders project into the air stream. This view shows details of attachment by tubular struts to fittings on the wing beams or spars. The points of attachment form a triangle, there being two V shaped struts in front and one in the rear, the apex being fastened to the wing.

A recently announced three-engined Junkers plane has passenger accommodation for twelve and is fitted with three engines developing 280 horsepower each, or 840 horsepower in all, is, said to be in regular operation over the newly established Elbe route from Hamburg to Dresden. The power available in this design is of the order of 70 horsepower per passenger with all engines at full throttle, a condition which will not be present in cruising because one of the advantages of a tri-motor plane is that the full power of all engines will not be normally required. Assuming a cruising condition at three-quarters throttle, this figure becomes 52 horsepower per passenger. Now, comparing these figures with those of an efficient single engined commercial airplane, it is possible to formulate some idea of the actual price to be paid for the safety and reliability features joined in the three-engined design. The De Haviland 54, fourteen

passenger plane, put in service by Imperial Airways, on the London-Paris route, is fitted with an engine rated at 600 horsepower which at full throttle represents 43 horsepower per passenger, while cruising on three-quarters power will put this figure at 32 horsepower per passenger. The single engined plane, it must be remembered, is liable to let its load of passengers down at any minute either over the water or the land, and though it must, and frequently does when such an event happens, land with perfect safety. On the other hand, we have the three-engined plane, capable of continuing flights with any one engine stopped, placing the reliability of travel by air upon a sound basis. And it will be seen, that the price to be paid for safety though not by any means small, is certainly not excessive and as such planes are further developed aerodynamically it is possible that it will

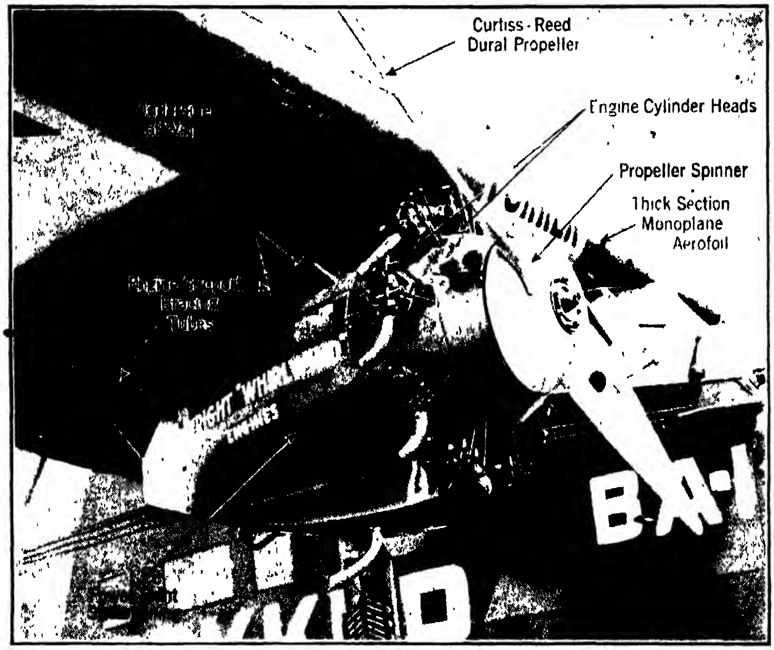


Fig. 113.—How Outboard Whirlwind Motors are Installed in the Fokker F VII Tri-Motored Monoplane. Note Effective Cowling and Streamlining, also Use of Metal Propeller with "Spinner" over Hub to Provide Good Streamline Entry for Power Plant.

not be more than 15 to 20 horsepower per passenger. Even if the cost of transportation was higher than in single engine planes, it is reasonable to assume that the promise of almost absolute safety from accidents due to engine failure would be enough to charge passengers a slightly higher rate, and that no reasonable person would refuse to pay more for transport in a safe plane, considering the excess tariff in the nature of insurance.

Airplane Engine Installation.—The proper installation of the airplane power plant is more important than is generally supposed, as while these engines are usually well balanced and run with little vibration, it is necessary that they be securely anchored and that various connections to the auxiliary parts be carefully made in order to prevent breakage from vibra-

tion and that attendant risk of motor stoppage while in the air. The type of motor to be installed determines the method of installation to be followed. As a general rule the six-cylinder vertical engine and eight-cylinder "V" type are mounted in substantially the same way. The radial, fixed cylinder forms and the radial, rotary cylinder Gnome and Le Rhone rotary types require an entirely different method of mounting. The usual form of engine bed for a fixed cylinder engine is shown at Fig. 116.

In a number of airplanes of the tractor-biplane type the power plant installation is not very much different than that which is found in automobile practice. The illustration at Fig. 118 is a very clear representation of the method of mounting the Curtiss eight-cylinder 90 H.P. 0x5 engine in the

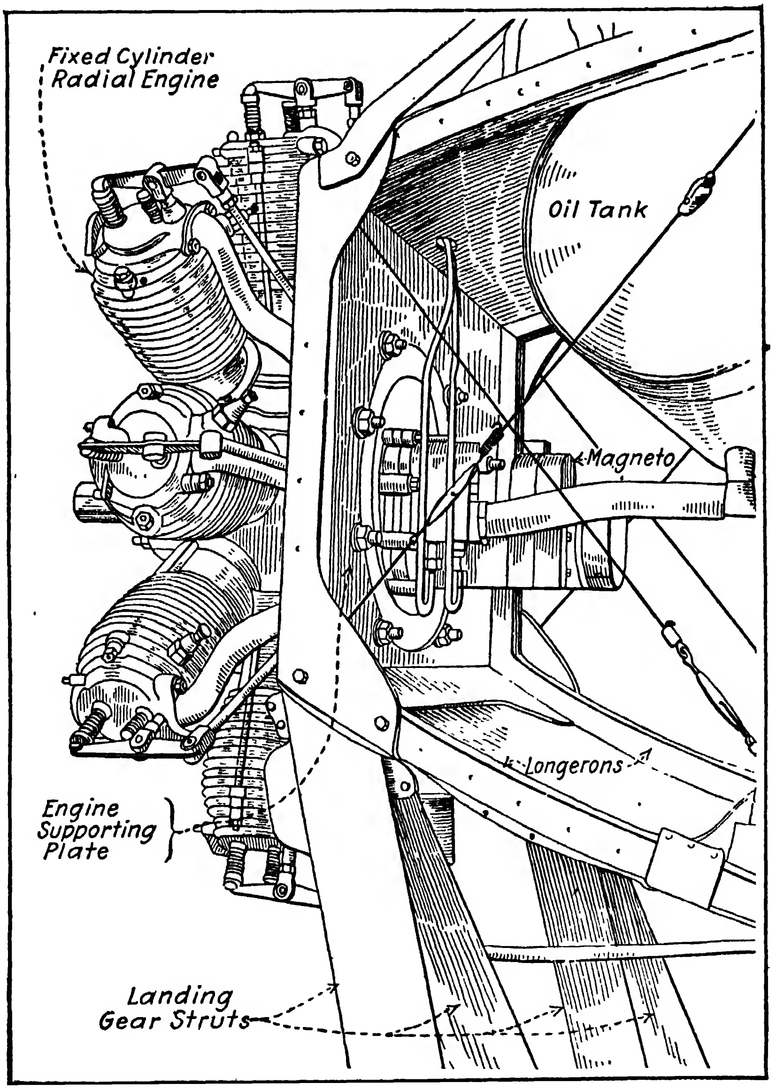


Fig. 114.—Anzani Ten-Cylinder Engine Installed in Fuselage.

fuselage of the Curtiss tractor-biplane which was so generally used as a training machine and which is still in use by many civilian flyers. It will be observed that the fuel tank is mounted under a cowl directly behind the motor and that it feeds the carburetor by means of a flexible fuel pipe. As the tank is mounted higher than the carburetor, it will feed that member by gravity. The radiator is mounted at the front end of the fuselage and connected to the water piping on the motor by the usual rubber hose connections. An oil pan is placed under the engine and the top is covered with a hood just as in motor car practice. Panels of aluminum (not shown in cut) are attached to the sides of the fuselage and are supplied with doors

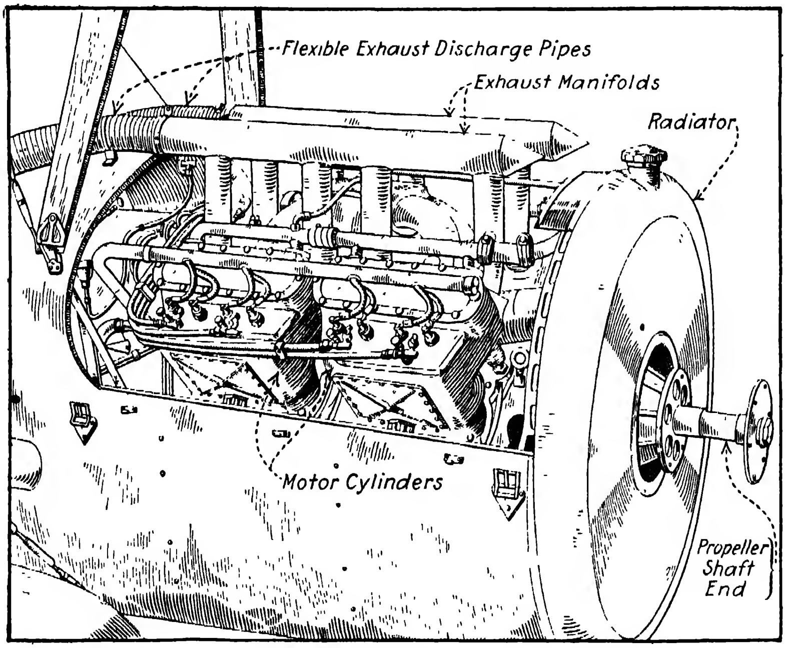


Fig. 115.—Showing Engine Installation in Monocoque Fuselage.

which open and provide access to the carburetor, oil-gauge and other parts of the motor requiring inspection. A complete installation with the power plant enclosed is given at Fig. 115, and in this it will be observed that the exhaust pipes are connected to discharge members that lead the gases away toward the rear of fuselage. In the engine shown at Fig. 118 the exhaust flows directly into the air at the sides of the machine through short pipes bolted to the exhaust gas outlet ports. The installation of the radiator just back of the tractor screw insures that adequate cooling will be obtained because of the rapid air flow due to the propeller slip stream. The engine installed in the airplane shown in Fig. 119 B is a four-cylinder type and the radiator is mounted above the motor instead of in front, a method of installation that is seldom followed on the later type airplanes where every effort is made to use radiators streamlined either into the fuselage or wing section to reduce parasitic resistance. The method of radiator mounting shown at Figs. 115, 118 and 119 B are practical ones for

relatively low speed training planes, but the exposed frontal area is so large that one must employ some other type of radiator where high speeds are desired without undue expenditure of engine power. Attention is directed to the radiator location on the Curtiss Hawk seaplane shown at Fig. 119 A. It is carried below the fuselage and well back in the slipstream.

Radiator Location Important.—Samuel R. Parsons, of the U. S. Bureau of Standards, in a paper read before the S. A. E. considers the location of the radiator and its influence on power required or absorbed to overcome its resistance and also the effect on heat dissipation of various radiator locations. In considering the performance of the radiator, it is convenient

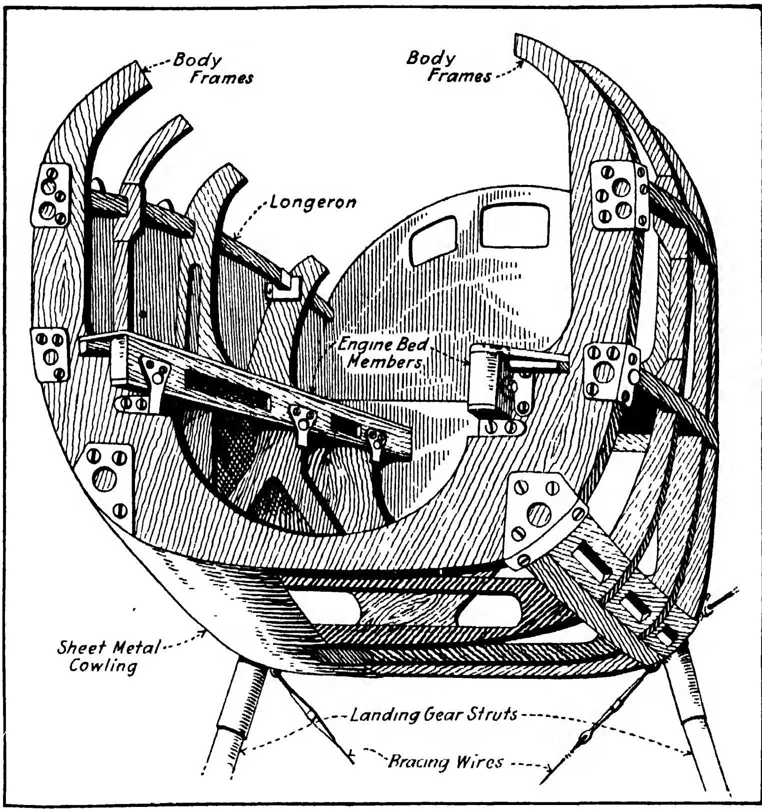


Fig. 116.—Engine Bed Construction in Typical German Airplane.

to divide the possible positions in which it can be mounted on the plane into three classes (*a*) unobstructed, in which the flow of air through and around the radiator is unaffected by other parts of the plane; (*b*) obstructed, in which the flow of air through the radiator is reduced by the effects of other parts of the plane; and (*c*) slipstream positions, in which the blast from the propeller blows over the radiator. It will be noted that slipstream positions include both those that would be obstructed, except for the propeller, and those that would be unobstructed.

The fundamental requirement for a radiator for an airplane engine is

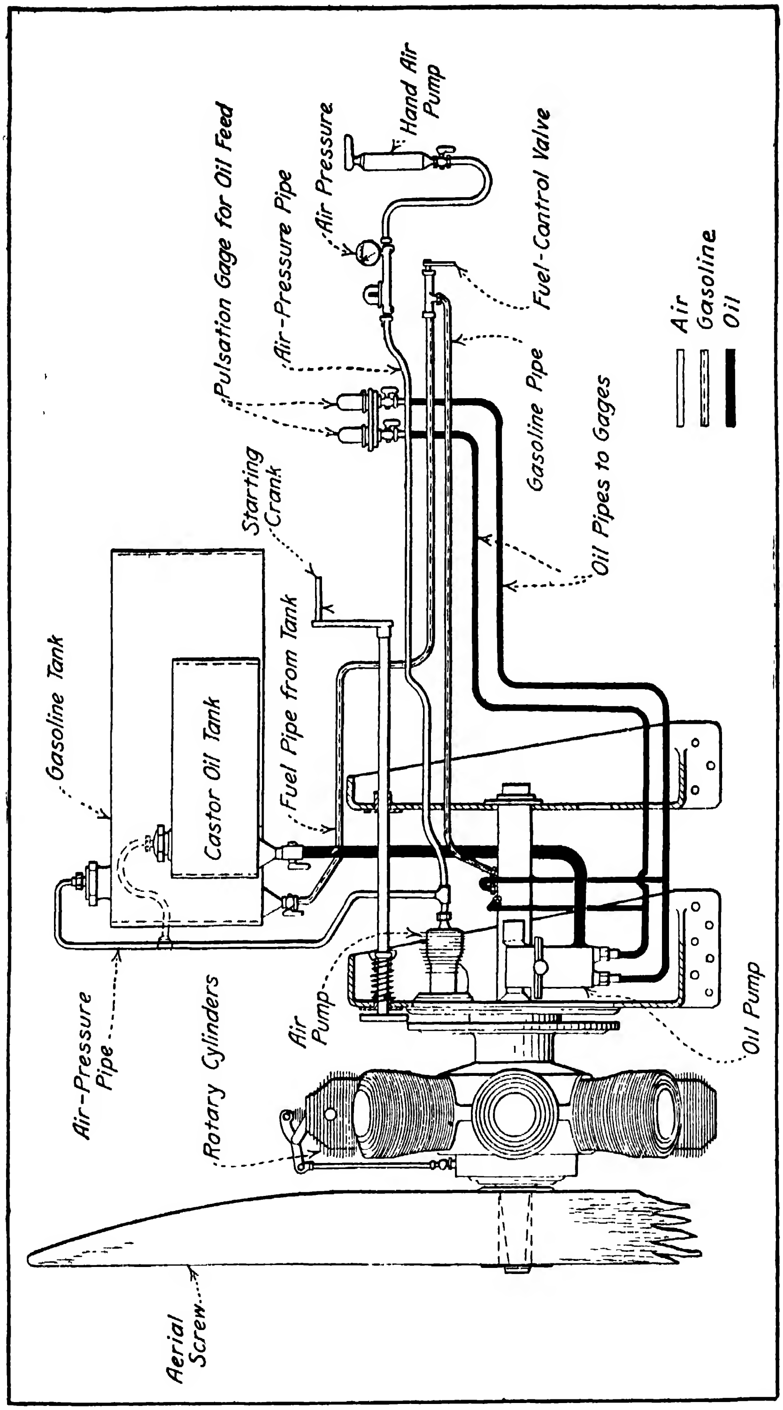


Fig. 117.—How Early Type Rotary Motor was Installed, Showing Air, Fuel and Oil Lines. This Type of Motor is Seldom Used in Modern Airplanes.

that it shall maintain the temperature of the water in the cylinder jackets within a limited range. In so doing it must dissipate heat under conditions that vary between wide limits. The speed of the airplane and consequently the rate at which air passes through the radiator are much greater for level flight at full throttle than for maximum rate of climb. Atmospheric temperatures vary widely between summer and winter, and between the ground and great altitudes; also, the density of the air falls off rapidly with altitude, being about one-half as great at 20,000 feet as at the ground. If a supercharging engine is used, the maximum speed of level flight may be considerably higher at great altitudes than near the ground.

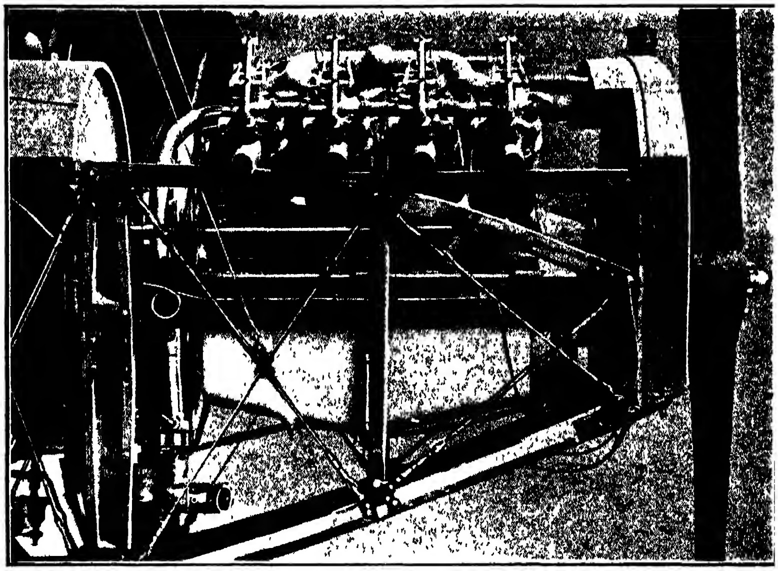


Fig. 118.—How OX5 Airplane Engines are Installed in Fuselage, Using Nose Type Radiator for Cooling.

With the use of supercharging engines, the most severe conditions for the radiator may occur at great altitudes. Since in general the most severe conditions for the radiator are those of climb at the maximum rate near the ground, the radiator is usually designed for this condition and provided with some means for shuttering, to control its cooling capacity when under less severe conditions. But while a capacity for dissipating heat to the atmosphere is the primary requirement of the radiator, it becomes necessary in aeronautic work to give very careful consideration to the effects of the radiator on the airplane. First, it adds somewhat to the weight to be carried; second, it adds considerably to the air resistance of the airplane. That is, more power is required to drive the plane than would be needed if it could be operated without a radiator. The force required to push the radiator through the air, called its head resistance, is considerable at high speeds. For many of the types of radiator submitted for aeronautic use it is so great that if an airplane were driven at 120 m.p.h., a radiator large enough to cool the engine would absorb from 12 to 15 per

cent of its power. The radiator causes absorption of power in two ways, in carrying its weight and in overcoming its head resistance. It also has other adverse effect on the plane, among which are (*a*) obstruction of the pilot's view, (*b*) modifications in internal construction of the fuselage to accommodate the mounting of the radiator, and (*c*), in military machines, liability to injury from hostile fire.

Resistance of Radiators.—The head resistance of the radiator can be assumed, for usual purposes, proportional to the square of the flying speed and to the density of the air. For unobstructed positions it may be represented by the equation

$$R = b\,p\,V^2 \text{ where}$$

R = the head resistance in pounds per square foot, or kilograms per square meter, of frontal area
V = the airplane speed in miles per hour, or in meters per second
p = the air density in pounds per cubic foot, or grams per cubic centimeter
b = a constant for each type of radiator.

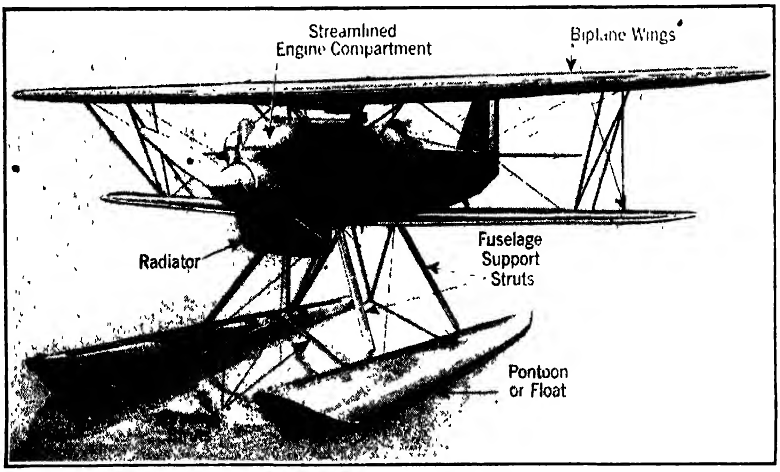


Fig. 119A.—Curtiss Hawk Seaplane, Navy Type F 6C-2 has Effective Radiator Placing. Note Streamlining of Engine Giving Minimum Resistance at Front End of Fuselage.

The value of b ranges between very wide limits. If the English units are used, for cellular radiators with straight-sided air tubes, it ranges from 0.0009 for cores with very large free area to 0.0023 for types with very small free area; for fin-and-tube radiators, unless very open, it exceeds 0.0020; and for irregular types with turbulence vanes it may run as high as 0.0026. The corresponding values for the metric units are respectively 1.4, 3.5, 3.1 and 4.0.

When the radiator is placed in the nose of the fuselage as in Figs. 115 and 118 the head resistance chargeable to the radiator, meaning the difference between the head resistance of the complete airplane and the resistance that it might have had if it could have been designed without a radiator, is in general very large and, for a given flying speed, the head

resistance chargeable to the radiator increases with increase in air flow. It is considerably greater for a radiator placed in the nose of the fuselage than when the nose of the fuselage is streamlined and a radiator of equivalent cooling capacity is placed in an unobstructed position as in Fig. 119 A. A radiator placed in the wing increases, in general, the resistance, or drag, of the wing, but the increase is not large and there may even be a decrease at certain angles of attack. The radiator, unless shuttered, will inevitably decrease the lifting power of the wing because no vaccum lifting effect is present above that section of the wing where the radiator is installed and very little positive lift is obtained because of air flow through the radiator.

If the radiator is placed in the slipstream, the head resistance chargeable to it is probably approximately equal to what it would be if the propeller could be removed and the airplane driven by some other means at such a speed as would give the same speed of air relative to the radiator. If this is true, the assumption that the speed of the slipstream relative to the radiator is from 20 to 25 per cent greater than the flying speed would apply to head resistance as well as it does to air flow. Since head resistance varies as the square of the speed, an increase of 20 per cent in speed results in an increase of 44 per cent in resistance. The effect of the swirl of the slipstream is similar to that of yawing the radiator, which is to increase the head resistance for unobstructed positions and for positions that would be unobstructed but for the propeller. For positions that would be obstructed without the propeller, as in the nose of the fuselage, the effect of the swirl of the slipstream is to make the air flow somewhat less than it would be if there were no swirl and, since for such positions the head resistance chargeable to the radiator increases with increased air flow, the effect of the swirl probably compensates to a slight extent for the effect of the increased speed of air due to the propeller.

Power Absorbed by Radiator.—Since in this paper the power absorbed is reduced to unit frontal area, the statements apply to the power absorbed by a given radiator, rather than to the power absorbed in cooling a given engine. The power absorbed is composed of two parts: that due to head resistance and that due to weight. Since the head resistance varies approximately as the square of the flying speed, and the power can be measured by the product of a force and a velocity, the power absorbed due to head resistance varies approximately as the cube of the speed. Since, however, the weight is sustained by a "lift" on the wings, which is a constant and equal to the weight, and since this is accompanied by a "drag" that is proportional to the lift for a given angle of attack, the power absorbed due to weight is more nearly proportional to the first power of the speed, and is dependent upon the lift/drag ratio of the airplane. The power absorbed can be computed from the equation

$$P = k\left(R + \frac{W}{r}\right)V \text{ where}$$

P = the power absorbed in horsepower per square foot, or kilowatts per square meter, of frontal area

R = the head resistance in pounds per square foot, or kilograms per square meter, of frontal area
w = the weight of the core and the contained water in pounds per square foot, or kilograms per square meter, of frontal area
r = the lift/drag ratio of the airplane
V = the flying speed in miles per hour, or meters per second
k = a conversion factor which is 0.00267 for the English units and 0.00980 for the metric units.

For speeds below 60 m.p.h., or 30 meters per second, the weight is of considerable importance in comparison with the head resistance, but as the speed increases it becomes relatively less important for speeds as high as 100 m.p.h., or 45 meters per second, the difference in weight between one radiator and another is of but small importance. Attention is called to the three classes of positions already defined. The unobstructed positions have the following advantages:

(1) Except for the effects of the slipstream, the airflow through the core, and consequently the heat transfer, are greater for unobstructed than for obstructed positions.
(2) The head resistance chargeable to the radiator is considerably less for unobstructed positions than for positions in the nose of the fuselage, in the wing or inside of the fuselage. The effect of the slipstream is to increase the head resistance of a radiator that would otherwise be unobstructed.
(3) Since airflow is greater in unobstructed than in obstructed positions and, therefore, heat transfer per unit frontal area is greater, it follows that the weight of a radiator may be less for a given cooling capacity when in an unobstructed than when in an obstructed position.
(4) With reduction both in weight and in head resistance chargeable to the radiator, the power absorbed chargeable to the radiator is reduced by placing the radiator in an unobstructed position, rather than in an obstructed position.
(5) With both increase in heat transfer and decrease in power absorbed, the figure of merit of an unobstructed radiator is considerably greater than that of the same type of radiator in an obstructed position.

The location of the radiator in the nose of the fuselage is objectionable because of very large absorption of power for a given cooling capacity. Not only is the resistance of the airplane much greater with a nose radiator than with the nose properly streamlined and an unobstructed radiator of equivalent cooling capacity added, but the airflow through the core is so low that with engines of the higher powers it becomes necessary to enlarge the fuselage to accommodate a nose radiator of sufficient size to cool the engine. The performance of a radiator in the wing as shown in Fig. 120 has not been thoroughly investigated because of experimental difficulties, but enough data are available to show that the airflow, and consequently the heat transfer, are very low for a given flying speed, while

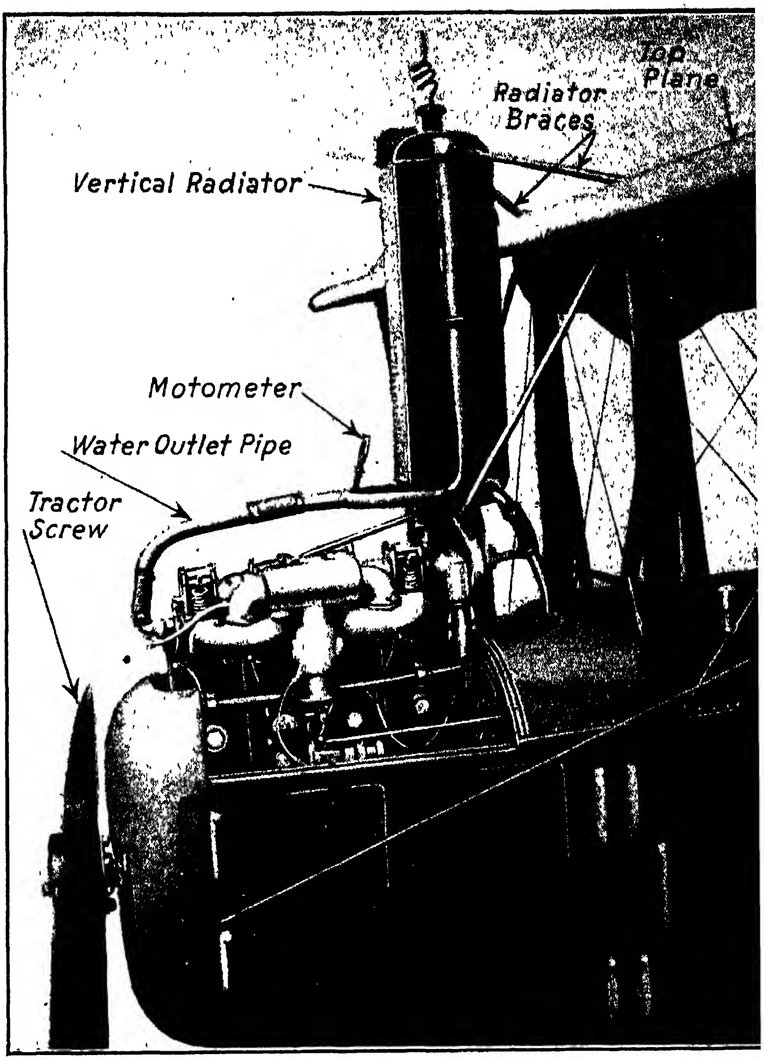


Fig. 119B.—How Early Hall-Scott Airplane Engines were Installed in Standard Training Plane. Note Vertical Radiator Placed above the Engine.

the effect on the wing as such can only be detrimental. Sometimes, the radiator is mounted in the center section and is built into the center section upper wing leading edge as shown at Fig. 120 A.

Heat transfer depends upon (*a*) the temperature difference between the air and the water; (*b*) the rate of flow of air through the air pasages, and (*c*) the rate of flow of water through the water passages.

For the temperatures involved in the use of water-cooled radiators, heat transfer can be assumed to be proportional to the mean temperature difference between the air and the water. For practical purposes it can be regarded as proportional to the difference between the average of the temperatures of the water at entrance and exit and the temperature of the entering air. For a given temperature difference between air and water,

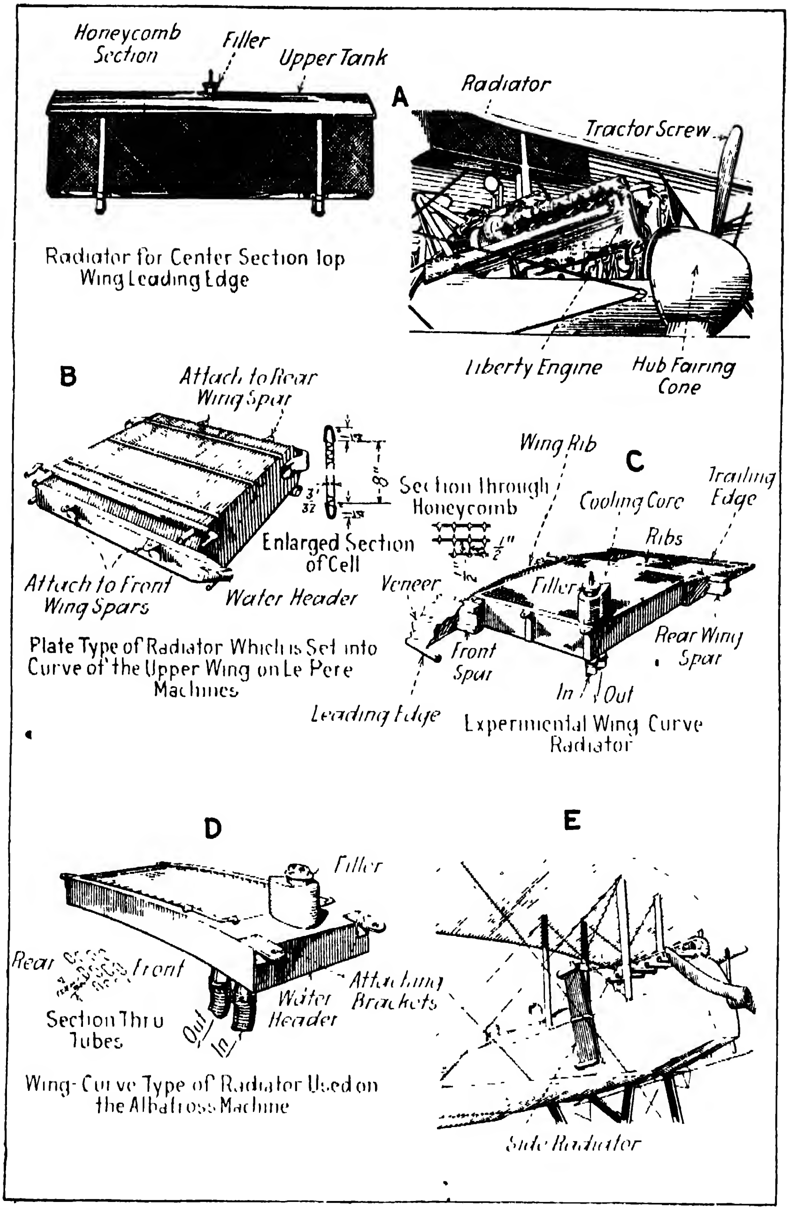


Fig. 120.—Various Practical Radiator Locations when Water-Cooled Engines are Used for Power. A—Radiator for Center Section Top Wing Leading Edge and its Installation. B—Le Pere Plate Type Radiator to be Set in Wing. C—Experimental Wing Curve Radiator Showing its Placing between Front and Rear Spars. D—Wing Curve Radiator Used on German Albatross Airplanes. E—Application of Side Radiators to Early Training Plane.

the heat transfer increases with the rate of waterflow, when the rate is low but, at the rates commonly used in aeronautic practice, heat transfer is not far from the maximum than can be obtained with change in waterflow and can be regarded as practically independent of that rate.

The special types of core include radiators made of water tubes in the form of flat hollow plates placed edgewise to the air stream and with no indirect cooling surface. This type shown at Fig. 120 has been shown to be markedly superior in respect to heat dissipation per horsepower absorbed, over the ordinary types of cellular radiator for use in unobstructed positions on planes flying at the higher speeds. The mechanical weakness of the flat-plate type is an inherent disadvantage, but one that can doubtless be overcome. Radiators of the fin-and-tube type show very high head resistance and low airflow; for this reason they are unsuited for general aeronautic use.

The free area is the fractional part of the frontal area of the core that is open for the passage of air. For use in unobstructed positions a large

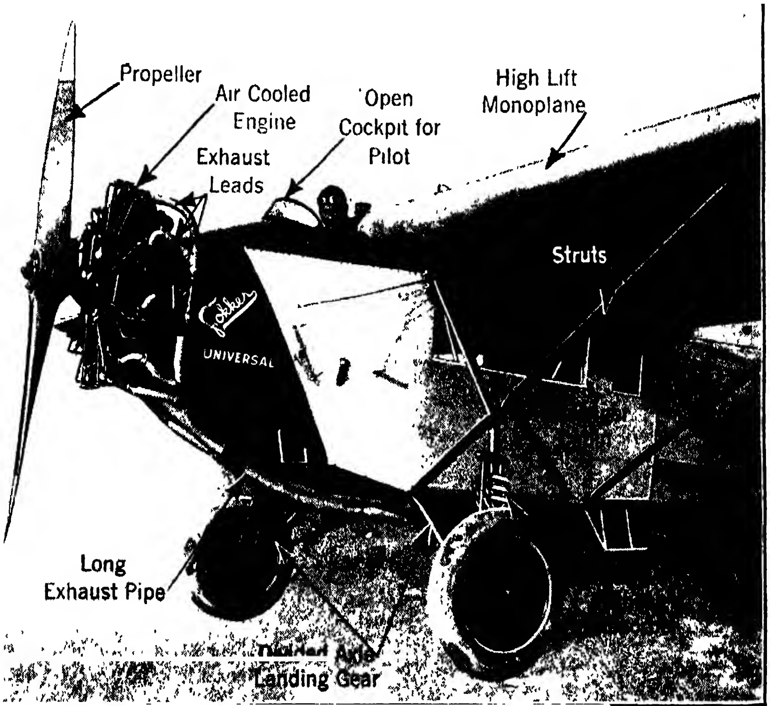


Fig. 121.—How Wright Whirlwind Air-Cooled Radial Engine is Installed in Fokker Universal Monoplane. Note Method of Exhaust Gas Disposal and Silencing.

free area is desirable to increase the airflow and decrease the head resistance, and should be sacrificed only for the sake of compactness of the radiator. Means of adjusting the amount of radiation while in flight possess considerable advantage. This adjustment may be made in two general ways: By regulating the flow of water through the radiator with the aid of a by-pass. By regulating the flow of air through the radiator. Both methods have been used successfully, but the first introduces the danger of freezing the water in the radiator.

The second method may be applied in various ways: By the use of shutters in front of the radiator. By drawing the radiator partly inside of

the body of the machine. By pivoting the radiator so that it may be set at varying angles to the air.

No one of these methods can be selected as the best since the choice of any one is dependent upon the installation of the radiator. In the case of a radiator located on the fuselage nose, the shutter system is the most suitable, as the resistance of the body is decreased when the shutters are closed.

Standard S. A. E. Engine Bed Dimensions.—The Society of Automotive Engineers have made efforts to standardize dimensions of bed timbers for supporting power plant in an airplane. Owing to the great difference in length no standardization is thought possible in this regard. The dimensions recommended are as follows:

Distance between timbers	12 in.	14 in.	16 in.
Width of bed timbers	1½ in.	1¾ in.	2 in.
Distance between centers of bolts	13½ in.	15¾ in.	18 in.

It will be evident that if any standard of this nature were adopted by engine builders that the designers of fuselage could easily arrange their bed timbers to conform to these dimensions, whereas it would be difficult to have them adhere to any standard longitudinal dimensions which are much more easily varied in fuselages than the transverse dimensions are. It, however, should be possible to standardize the longitudinal positions of the holding down bolts as the engine designer would still be able to allow himself considerable space fore-and-aft of the bolts.

Installing Rotary and Radial Cylinder Engines.—When rotary engines are installed simple steel stamping or "spiders" are attached to the fuselage to hold the fixed crankshaft. Inasmuch as the motor projects clear of the fuselage proper there is plenty of room back of the front spider plate to install the auxiliary parts, such as the oil pump, air pump and ignition magneto and also the fuel and oil containers. The diagram given at Fig. 117 shows how a Gnome "monosoupape" engine is installed on the anchorage plates; and it also outlines clearly the piping necessary to convey the oil and fuel and also the air piping needed to put pressure on both fuel and oil tanks to insure positive supply of these liquids, which may be carried in tanks placed lower than the motor in some installations. The simple mounting possible when the Anzani ten-cylinder radial fixed type engine is used is given at Fig. 114. The front end of the fuselage is provided with a substantial pressed steel plate having members projecting from it which may be bolted to the longerons. The bolts that hold the two halves of the crankcase together project through the steel plate and hold the engine securely to the front end of the fuselage. The installation of a Wright nine-cylinder, Whirlwind engine at the front end of the fuselage of a Fokker "universal" monoplane is clearly shown at Fig. 121. Rotary engines are practically obsolete because of the limited rotational speeds possible and also because of the power consumed in overcoming the air resistance to the rotating cylinders. The modern fixed cylinder radial engines are much more efficient and desirable power plants so it is doubtful if the rotary type will ever be used to any extent in modern airplanes.

TABLE XIV

Characteristics of Typical American Pre-War Aviation Engines

Maker's Name and Model	Number of Cyl.	Bore (inches)	Stroke (Inches)	Piston Displacement (Cubic Inches)	H.P.	R.P.M.	Weight of Engine with Carburetor and Ignition	Gas Consumption
Curtiss OX	8	4	5	502.6	90	1400	375	10 gals. per hour
Curtiss OXX-2.......	8	4¼	5	567.5	100	1400	423	11 gals. per hour
Curtiss V-2...........	8	5	7	1100	200	1400	690	....
Duesenberg A-4.......	4	4¾	7	496	140	2100	455	....
General Vehicle Gnome Mono (Rotary Air-Cooled)	9	4.33	5.9	848	100	1200	272	12 gals. per hour at rated H.P.
Hall-Scott A-7........	4	5	7	550	90–100	1400	410	....
Hall-Scott A-5........	6	5	7	825	125	1300	592	....
Hispano Suiza........	8	4⅝	5	672	154	1500	455	....
Sturtevant 5-A........	8	4	5½	....	140	2000	514	13.75 gals. per hour
Thomas 8............	8	4	5½	552.9	135	2000	630 with self-starter	0.59 lbs. per B. H. P. hr.
Thomas 88...........	8	4⅛	5½	552.9	150	2100	525 lbs. with self-starter	0.59 lbs. per B. H. P. hr.
Wisconsin	6	5	6½	765.7	140	1380	637	....

(Note.—Engines running at speeds in excess of 1500 R.P.M. have a reduction gear for driving propeller.)

TABLE XIV (continued)

Data on Post War Engines

Class, Hp.	Name	Type	Cooling	Number of Cylinders	Bore and Stroke, In.	Displacement Cu In	Horse-Power	Speed, R.P.M	Compression Ratio	Mean Effective Pressure, Lb. per Sq. In.	Weight, Lb.	Power plant Weight per Horse-power, Lb.[a]
200	Wright E-4	90-deg. V-type	Water	8	4.710x5.110	718	200	1,800	5.30	122	470	3.20
	Wright J-4-A.	Fixed Radial	Air	9	4.500x5.500	786	200	1,800	5.00	112	470	2.35
350	Wright R-1200	Fixed Radial	Air	9	... .	....	350	1,900	....	...	....	....
	Curtiss R-1454	Fixed Radial	Air	9	5.625x6.500	1,454	400	1,700	....	...	740	1.85
400	Standard Liberty	45-deg. V-type	Water	12	5.000x7.000	1,650	400	1,700	5.40	113	880	2.97
	Special Liberty	45-deg. V-type	Air	12	4.625x7.000	1,412	400	1,800	....	124	940	2.35
450	Wright P-2	Fixed Radial	Air	9	6.000x6.500	1,650	450	1,800	5.00	120	820	1.82
500	Curtiss V-1400	60-deg. V-type	Water	12	4.875x6.250	1,400	500	2,100	6.25	134	660	2.09
	Packard 1A-1500	60-deg. V-type	Water	12	5.375x5.500	1,497	500	2,000	5.50	...	720	2.20
600	Wright T-3-A	60-deg. V-type	Water	12	5.750x6.250	1,947	600	2,000	5.40	122	1,150	2.79
800	Packard 2500	60-deg. V-type	Water	12	6.375x6.500	2,489	800	2,000	5.70	127	1,150	2.39

[a] Fuel and oil weights were not included as many were unobtainable.

Saving weight is the most important characteristic of air-cooled engines for aviation. Air-cooled engines save directly the weight of radiator, piping, water, pumps, shutters and radiator supports. Furthermore, there is saved in the plane structure itself the weight necessary to carry this water radiation equipment. This last saving is very important, as it runs from 50 per cent to 100 per cent of the direct saving. For instance, compare the weights and performances of air-cooled vs. water-cooled, two-seater planes built by the Chance Vought Corporation, both powered with Wright 200 H.P. engines. The air-cooled plane saves 145 pounds on radiator, shutters, piping and water and over 70 pounds more in plane structure. This weight saving has been applied to give the air-cooled plane higher speed and greater radius, without loss of ceiling or increase of landing speed. The air-cooled engine has increased the speed 18 m.p.h. or 15 per cent, and increased the cruising radius 150 miles or 51 per cent, nothwithstanding the air-cooled planes carries 89 pounds more equipment than the water-cooled plane.

Air-cooling is as logical for airplanes as water is for marine engines. Its simplicity, on account of the direct cooling, results in added dependability. This is the single most important reason for air-cooling. In addition, a considerable saving of weight is effected that amounts to approximately 0.7 pounds per horsepower in the total power plant weight. In no other way, at present, can this amount of weight be removed from the power plant and at the same time increase its dependability. The reduction in power plant weight is reflected in the airplane, both in the structure of the fuselage and in the wing surface for a given loading. The reduction in the gross weight of the airplane is of the utmost importance for commercial operation, as it provides for carrying more pay-load with a given power plant. From a military standpoint, this saving results in increased airplane performance. In addition to increased dependability and reduced weight, the radial type of air-cooled engine makes possible an aerodynamically superior and symmetrical fuselage, and gives a high center of thrust that allows ample propeller-diameter.

Captain Robert W. A. Brewer, a member of the S. A. E. and an aeronautical engineer of note with much experience on power plant design and installation recently published some observations on radial air-cooled engine installations in Aviation that should be of interest to the reader. He wrote, in part, as follows:

"In arranging the installation of an air-cooled engine, proper means must be provided for getting rid of the hot air readily.

As the type of engine under discussion has so much in its favor with regard to cost of production, ease of overhaul, accessibility, etc., none of these advantages should be minimized by fitting an unsuitable mount and every consideration should be given to this aspect of the subject. There is, at present, no standardized method of mounting. Similar airplanes use different mounts and because the possible adaptations are so wide, we cannot, at this period, set up a standard, and must be content with certain points for guidance.

The engine maker requires that:—

(1) The mount should be light and strong enough to support the engine without suffering from serious deflection under working conditions. It should be properly braced in all bays.
(2) It must be rigid in itself to withstand the torque variations in the engine and any periodic vibrations in the mounting must not synchronize with any that the engine may have throughout its working range of speed.
(3) The mounting must not set up stresses in the crankcase or in the ends of the fuselage. If attached by pins to the fuselage, the pins should have very ample bearing surfaces and preferably be tapered and ground.
(4) A spigot mounting plate, if used, should be true and a good fit.
(5) There should be no interference with the accessibility of those parts or details which are likely to require attention periodically. The complete removal as a whole, of the engine and mounting or engine only, should be readily possible. This should only necessitate the disconnection of a few oil, gasoline lines, and the tachometer drive.

A few details, due to Roy Fedden, designer of the Jupiter engine, are available and instructive with regard to weights. The following figures relate to the same airplane with different engines:

	RADIAL AIR-COOLED	WATER-COOLED			
Lb. per b.hp.		a.	b.	c.	d.
(Total installed weights)....	2.00	2.89	3.21	2.74	3.35
Per cent per b.hp. of weight of installation	100	144.5	160.5	137	167.5

Another tabulation gives valuable details of the weights of mountings and cowlings:

		type	lb./b.hp. mounting	lb./b.hp. cowling
two seater	.300	8 vee W.C.	.186	.116
two seater	.240	6 cyl. W.C.	.22	.125
two seater	.270	12 vee W.C.	.144	.150
two seater	.300	9 rad A.C.	.062	.049
twin engine	.380	9 rad A.C.	.087	.073

In small machines, the advantage of possible weight reduction can be fully taken for the radial engine for this is a favorable opportunity. Generally, we find that some form of ring is provided for the immediate attachment of the engine. The ring is supported from the front of the fuselage by a system of struts suitably triangulated to give stiffness to the structure. Various forms of radial engine mounts suggested by Captain Brewer are shown at Fig. 122. Thus, the engine can be held away from the fire bulkhead a sufficient distance not only to give free access to the accessories mounted at the rear of the engine, but also to provide enough room for the heated air to be led away in a free manner. In some installations a four point support is given to the ring by tubular members, while in others, where production quantities are considered, pressings of steel or

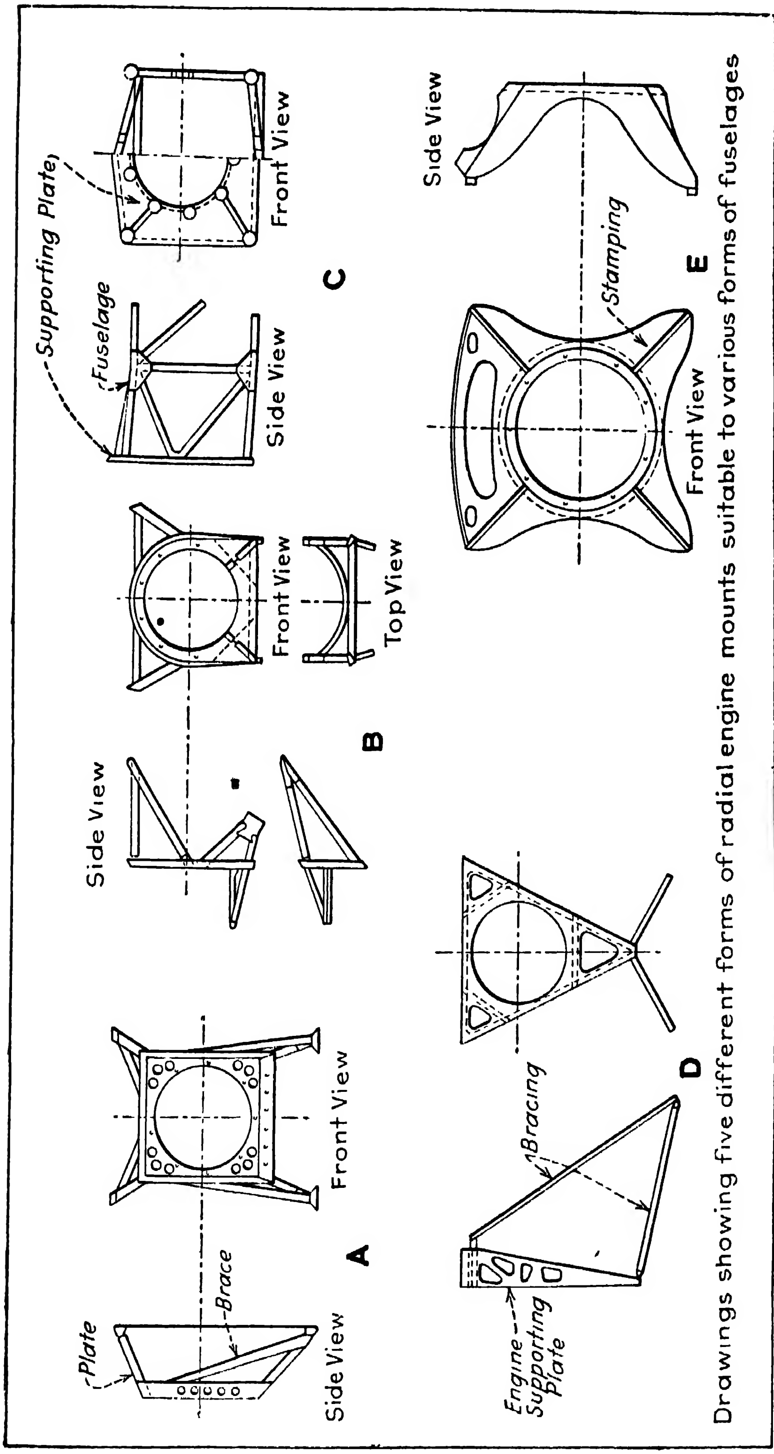


Fig. 122.—Drawings Showing Five Different Forms of Radial Engine Mounts for Various Forms of Fuselages.

duralumin provide a suitable and workmanlike set of supporting arms. In some arrangements the mounting ring is removable with the engine, while in others the ring forms part of the structure and the engine is removable from it. The swinging form of front mount is sometimes employed and, although it has not come generally in favor, it shows possibilities. The method of mounting a radial engine outboard is shown at Fig. 113 which also shows cowling and streamlining.

When a radial engine is used as a replacement on a plane designed originally for a straight-line engine, the required center of gravity position of the plane automatically calls for a considerable space between the rear of the engine and the fire bulkhead. We are thus led to the question of a suitable cowling. Generally, with radials as designed at this time, the

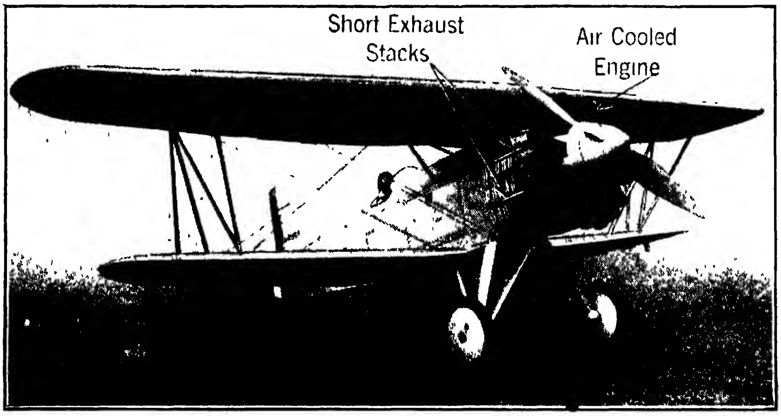


Fig. 123.—Curtiss Hawk Navy Plane with Pratt and Whitney Wasp Motor Installed Showing Short Stack Exhaust Used on Service Planes.

forward part of the cowling can be a more or less permanent structure, as the position of the major accessories is usually at the rear. Many radials are designed so that the front cover plate gives a good entrant form and scarcely requires a fairing. When this is so, oil-cooling by the slipstream can be taken advantage of. The rear part of the cowling must have easily removable panels between the engine mounting proper and the fire bulkhead. These should have proper stiffness and be so designed that local stresses are not set up as such as would cause fracture due to vibration. The Curtiss Hawk Navy type with Pratt and Whitney Wasp engine shown at Fig. 123 shows modern cowling practice. Generally, this part of the cowling must, in the first instance, be made on the job. The design of proper catches or fasteners leaves much scope for the designer. They should be readily detachable and preferably be some form of safety catch which will stay in place and which can be sunk into suitable depressions in the plates. As to the extent of the cowling and the amount by which it should cover the cooling fins on the engine, much depends upon the kind of general service which the plane will have to fill. Where much ground work and taxiing has to be done, the maximum air accessibility is desirable and the engine may be entirely without cowling as in the form shown at

Fig. 121. Some engines are too much cooled, so that almost complete cowling has been resorted to.

There is an intermediate, and very successful system where helmet cowls are provided for the individual cylinders. They have small front vizors and proper outlets at the rear. It is quite feasible to carry out some scheme such as this not only for individual cylinders but for the engine as a whole."

Combined with the matter of cowling, the handling of the exhaust is very important. There are two main considerations here,—nuisance from the noise and prevention of fire. It is apparently a moot point whether the provision of an exhaust ring manifold does or does not diminish fire risk. However, in Captain Brewer's opinion, much depends upon how the stack pipes leave the engine. Certainly the further they are from the carburetor inlet the better, as flame from the exhaust is very readily drawn into the carburetor inlet if it comes at all near to it.

Short stack pipes such as shown at Fig. 123 must be a nuisance to the pilot, particularly in the dusk, and modern progress calls for some form of silencing the noise especially on planes intended for passenger transport. Probably the best place for a ring manifold is in front of the engine and as near to the center as conditions will permit. The design of a suitable system has been full of difficulty and Mr. Fedden tabulates some factors to be considered in this connection.

(1) Light weight and the lowest drag possible.
(2) The system must be of sufficient volume not to cause back pressure and damage to the valves.
(3) There must be no sharp bends and the gases must not play directly upon any part of the expansion chamber.
(4) The pipes from the individual cylinders leading to the main chamber must be provided with flexible joints to allow for expansion of the cylinder heads.
(5) Welding to be used as little as possible and if necessary, riveting should be used as well.
(6) The system, as a whole, must be sufficiently rigid to withstand any serious distortion and robust enough for long service.
(7) The design must be such that it can be produced economically by press tools and jigs.
(8) The material must be such that it will resist corrosion.

The general conclusions seem to point to the fact that the exhaust outlet from the engine should be at the side of the cylinder, as from this location the stub pipes can be led forward or back. Proper air-cooling of the valve seats can be had, which is more difficult where the pipes lead out directly forward from the cylinder block. Outlets from the exhaust ring can conveniently be two in number,—one on either side near the bottom. By this arrangement the gas can be led away from the carburetor and follow the lines of the fuselage. An interesting study of a practical method of leading away the exhaust gas is that used in the Fokker Universal, shown at Fig. 121. Here we find a combination manifold consisting of cast elbows

at the cylinder heads with cast junction fittings, these being joined together with flexible exhaust tubing, the assembly terminating into a long exhaust discharge pipe carried under the fuselage. Not only are the exhaust gases effectively disposed of and fire risk greatly reduced but a pronounced silencing effect is obtained with minimum back pressure.

Designing Water-Cooled Engines Into Aircraft.—Most of the single engine airplanes of late design using water-cooled engines have power plants ranging from 400 to 600 horsepower, especially those intended for air mail or express or passenger carrying, and also the types for military service. Now that there are various types and makes of engines to select from, the engine is designed into the airplane instead of the structure being designed around the engine as was formerly done when only a few types of engines were available. The twelve-cylinder V type engine is by far the most popular and it can be had in direct drive and geared down types, as well as in designs that can be installed with the cylinders inverted. An important consideration is propulsive efficiency and the streamlining of the fuselage front end is important so that a minimum amount of the propeller disc area will be masked by the cowling around the engine.

There is also another influence and that is the vision obtained by the pilot directly ahead and also directly down to insure good landings. Effective streamlining of the Curtiss engine in the Hawk seaplane illustrated at Fig. 119 A reduces the loss of propulsive pull of the aerial screw by having a minimum masked area. The various airplanes shown at Fig. 124 show how the various types of engines may be installed to secure good streamlining, vision and reasonable aerodynamical efficiency. The conventional direct drive motor is installed in the structure shown at A. It will be seen that in order to obtain good vision that the engine crankshaft, which is also the center line of propulsive, or rather tractive effort comes well below the center of the biplane cellule, where one may assume the center of gravity of the entire structure to be located.

When a geared form of engine is installed, it will be apparent that with the same engine location as at A, Fig. 124, the center line of tractive effort is raised in B by raising the propeller drive shaft center line so it more nearly coincides with the assumed center of gravity. Besides the advantage of bringing the line of thrust higher, the type of engine shown in B permits of higher horsepower output for the same weight because the engine can be run faster and also makes for higher propeller efficiency because a larger diameter and slower screw can be used with a geared engine than with a direct drive form.

In a fast plane where maximum maeoeuverability is sought, as in the single seater shown at Fig. 124 C, a coincidence of the tractive effort line and the center of gravity is possible by using an inverted engine and aerodynamical efficiency is obtained without greatly sacrificing the factor of vision by carefully streamlining the front of the fuselage.

Air Resistance Characteristics of Engines.—Some interesting figures were given by Grover C. Loening, pioneer aeronautical engineer and inventor of the amphibian land and seaplane in a paper read before the S. A. E. in which some interesting conclusions were reached and results tabulated.

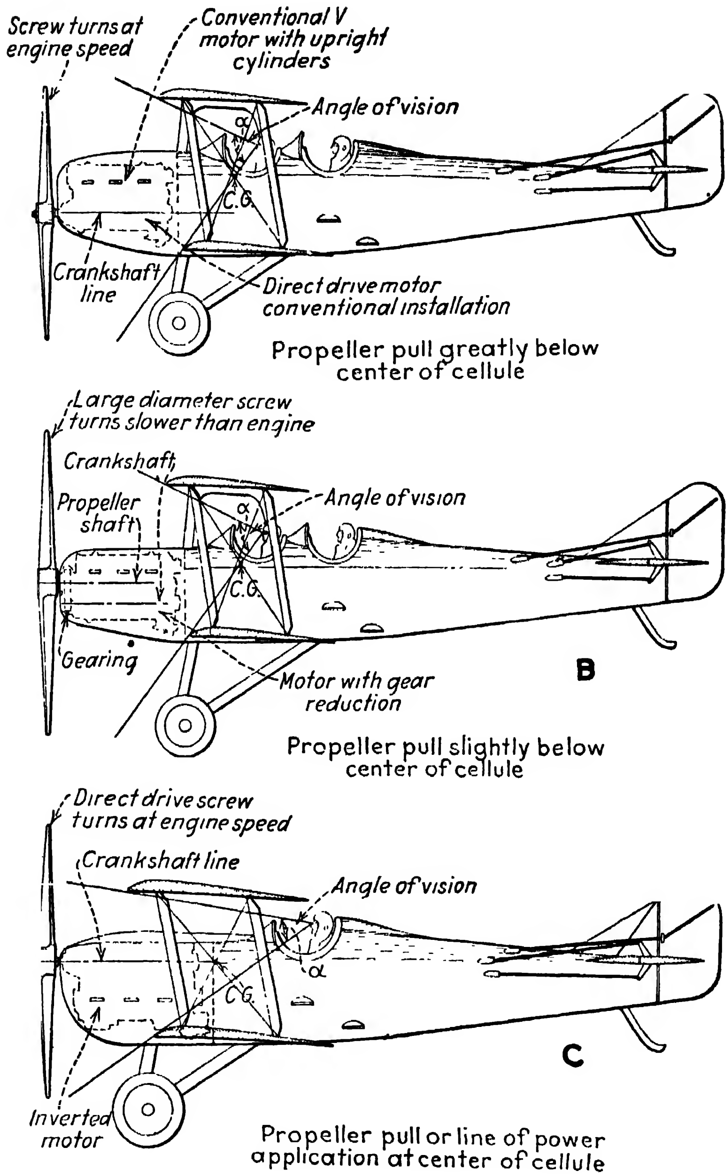


Fig. 124.—Diagrams Showing Installation of Various Types of Water-Cooled Engines in Fuselage to Secure Good Vision and Proper Aerodynamical Advantages. A—Direct Drive Propeller. B—Gear Drive Propeller. C—Inverted Crankshaft, Direct Drive Type.

One might condense the general sentiment of the aviation world with regard to fast machines by pointing out that the light-weight high-powered radial air-cooled engines are generally considered the coming type for small fast aircraft; while the large, heavy high-powered water-cooled engines are generally placed in large, slow, load-carrying airplanes. Further than this, there is a distinct tendency on the part of engine builders to sac-

rifice some details for the purpose of lightening the weight of the engine, "dry," in pounds per horsepower. The engine builder is only too likely to think that he has reached the goal required by the aircraft builder if he can make this figure low enough. Mr. Loening proposed to demonstrate that this attitude is not only erroneous, but actually tends to the development for aircraft of engines that are very undesirable for several important reasons.

Leaving for a moment consideration of fast aircraft from the airplane standpoint, Mr. Loening stated that the airplane engine must drive itself through the air, and requires some proportion of wing area to carry its own weight. Considering the power absorbed by the engine itself, we find that it consists of the head resistance of the engine and of its necessary water or oil radiators, due to their shape, and the drift on the wings that is chargeable to the weight of this power plant. To separate these two items and examine into the desirability of various engines for the attainment of high speeds, we must analyze the cost of head resistance due to a heavy engine as against a light engine, and add the cost of head resistance caused by a bulky or a streamlined engine as the case may be. Mr. Loening seeks to simplify this problem by making the following reasonable assumptions:

(1) In high-powered, carefully-designed aircraft engines, the fuel consumption per horsepower is very nearly the same.
(2) In applying maximum skill in airplane design, it is likely that the weight per horsepower of the airplane structure necessary to carry any of these engines will be about the same.
(3) The propeller efficiency of the various engines can be considered practically the same, because we are examining primarily the high-speed conditions where the advantage of the slow speed of the geared propeller does not enter and might even prove detrimental.
(4) In the drift of the wings necessary to carry any engine, the same lift/drift ratio can be assumed.

It will be found on analyzing these assumptions that they mean that we do not penalize engines by placing them in different types of aircraft, and are thus justified in considering figures on a unit horsepower basis.

It has been found quite conclusively on may types of aircraft using water-cooled engines that, no matter where the radiator is placed, a certain amount of head resistance must be expended to get cooling, since the air must pass through the radiator. Placing the radiator in front of an engine, in an effort to combine the resistance of the two, merely makes it necessary to add to the size of the radiator by exactly the amount that the presence of the engine behind it blocks circulation. This is particularly true of the Liberty engine when mounted on the De Haviland-Four. A review of the sizes of various well-placed radiators gives the values for frontal areas presented below.

This reduction in size of radiator, of course, involves the consideration that on a high-speed machine the radiator be retractable.

Speed, m.hp.	Frontal Area of Radiator, per Horsepower sq. in.	Lift/Drift Ratio
50	2.5	8 to 1
100	2.0	11 to 1
150	1.5	11 to 1
200	1.0	10 to 1

The weights of the engines shown in Table 15 are inclusive of radiator, water and propeller, complete. Part of the airplane's wing area must do its share of work in supporting the weight of the engine, and this work will cost a certain amount in head resistance represented by the drift of this proportion of the wing. We can arrive at this figure for any speed by dividing the weight of the engine by the lift/drift ratio at that speed, and from an examination of efficient wing structures the lift/drift ratios are assumed as in preceding tabulation.

In arriving at these values consideration has been given to the drift as a resistance not only of the wing section itself but of the complete bracing necessary to support it, which explains the less efficient value at 50 m.p.h. where flight would require a very large wing area and light wing loading which would necessitate a high head resistance in struts and wires.

The resistance of various fuselages measured in wind tunnels have been reviewed and found to differ considerably from the actual resistance of fuselages of full-size airplanes, as determined from their actual performances. This is probably due to the ignoring of the slipstream effect. At any rate, a review of all these figures indicates that in the formula $R = KSV^2$ the value of the resistance coefficient K, for most fuselages, averages about 0.0009, where cross-sectional area is expressed in square feet and the speed V in miles per hour. This value has been adopted for all engines.

Mr. Loening made some computations and presented a chart in developing his discussion that permitted an interesting demonstration when the figures for the Curtiss C-12 were used for an example and assumed first that by laborious work the weight of the engine was reduced to one-half its amount, which it is very doubtful could ever even be approached in this type of engine. Assuming such an extreme, however, we find the resistance per horsepower, when reduced as shown, permits an increase in speed from 232 to 241 m.p.h. or only 9 m.p.h. On the other hand, we can take this same engine and assume that, keeping its weight the same, we modify its structure so as to halve the head resistance of the engine itself, due to its shape. This change, which is entirely within the realm of possibility, would increase the speed to 290 m.p.h., and would show that if we could get a 420-hp. engine with a cross-sectional area permitting a good shape that would not be much over 2 feet high and 9 inches wide, we could approach a speed of 300 m.p.h. Even admitting that some of the assumptions made necessary to derive this line of reasoning are apt to vary, we nevertheless find a lesson of the greatest importance which promises much in the

TABLE XV

Air-Resistance Characteristics of Engines at Varying Speeds.

Name	Power hp.	Number of Cylinders	Weight with Radiator, Water and Propeller, lb.	Weight, lb. per hp.	Frontal Area, sq. ft.	50 m. p. h. Engine Resistance, lb.	50 m. p. h. Radiator Area, sq. ft.[6]	50 m. p. h. Radiator Resistance, lb.	50 m. p. h. Wing Drift Resistance, lb.	50 m. p. h. Total Resistance, lb.	50 m. p. h. Resistance per hp., lb.	100 m p h Engine Resistance, lb.	100 m p h Radiator Area, sq. ft.[6]	100 m p h Radiator Resistance, lb.	100 m p h Wing Drift Resistance, lb.	100 m p h Total Resistance, lb.	100 m p h Resistance per hp., lb.
Fiat[2]	700	12	1,970	2.82	6.22	14.0	12.0	36.0	246	296	.42	56	9.7	116	180	352	0.50
Rolls-Royce Condor[3]	650	12	1,400	2 16	7.32	16.5	11.3	34.0	175	225	0.35	66	9.1	109	127	302	0.47
Salmson[4]	550	18	1,120	2 04	10.10	22.5	9.5	28.5	140	191	0.35	91	7.6	91	102	284	0.51
Napier Lion	450	12	1,040	2.30	5.68	12 8	7.8	23.5	130	166	0.37	51	6 2	75	94	220	0.49
Curtiss C-12	420	12	830	1.97	4.66	10.5	7.3	22.0	103	136	0.32	42	5.8	69	75	186	0 44
Cosmos-Jupiter[5]	400	9	690	1.73	12.65	28 3	....	....	86	114	0 28	114	...	..	63	177	0 44
Liberty	400	12	1,090	2.74	5.16	11.6	7.0	21.0	136	169	0.42	47	5.6	67	99	213	0.53
Hispano-Suiza	300	8	810	2.69	4.75	10.7	5.2	15.6	102	148	0.49	43	4.2	51	73	167	0 55
BR-2	230	9	530	2.30	9.62	21.7	....	....	66	88	0.37	87	...	...	48	135	0.59
Hall-Scott, L-6.	230	6	630	2.75	3.87	8.7	4.0	12.0	79	100	0.43	35	3.2	38	57	130	0.56

Name	150 m p h. Engine Resistance, lb.	150 m p h. Radiator Area, sq. ft.[6]	150 m p h. Radiator Resistance, lb.	150 m p h. Wing Drift Resistance, lb.	150 m p h. Total Resistance, lb.	150 m p h. Resistance per hp., lb.	200 m. p. h. Engine Resistance, lb.	200 m. p. h. Radiator Area, sq. ft.[6]	200 m. p. h. Radiator Resistance, lb.	200 m. p. h. Wing Drift Resistance, lb.	200 m. p. h. Total Resistance, lb.	200 m. p. h. Resistance per hp., lb.
Fiat[2]	126	7.3	197	180	503	0 72	224	4.9	235	197	656	0.94
Rolls-Royce Condor[3]	148	6.8	184	127	459	0.71	264	4 7	226	140	630	0.97
Salmson[4]	204	5 7	154	102	460	0.84	362	3.8	182	112	656	1.20
Napier Lion	115	4.7	127	94	336	0 75	204	3.1	149	104	457	1.02
Curtiss C-12	94	4.4	119	75	288	0.69	168	2.9	139	83	390	0.93
Cosmos-Jupiter[5]	256	...	...	63	319	0.80	458	...	...	69	527	1.32
Liberty	105	4 2	104	99	308	0 77	186	2 8	135	109	430	1.08
Hispano-Suiza	96	3.2	86	73	255	0 85	171	2.1	101	81	353	1.17
BR-2	195	.	. .	48	243	1 05	346	...	...	53	399	1.73
Hall-Scott, L-6.	78	2.4	65	57	200	0.87	139	1.6	77	63	279	1.21

[2]Direct drive.
[3]Direct drive for high speed.
[4]Water-cooled; radial.
[5]Air-cooled; radial.
[6]The value of the frontal area of the radiator in square inches per horsepower developed by the engine for the different speeds and the lift-drift ratio or drift resistance are given in text.

future of aviation. This shows how much more important the head resistance of an engine is than its weight. Mr. Loening urged the builders, therefore, to abandon their unwarranted race for lighter weight per horsepower, bringing with it tremendous expense in construction, a lack of reliability and innumerable difficulties in service, and suggested that they begin on a new line offering far greater possibilities by making the shape and disposition of their engines more suitable to airplanes, with low head resistance considered as a fundamental. An engine of sufficiently well-studied shape will permit greater weight, more reliability, and less construction expense without a sacrifice of aerodynamical efficiency.

Mr. Loening has been an advocate of inverted cylinder V engines for some time past and the Amphibian, which is the product of his genius, uses an engine with the crankshaft placed above the cylinders. This type permits the use of a larger diameter tractor screw and also materially lowers the center of gravity of the power plant. Various engine types mentioned in Table 15 are shown in outline at Fig. 109.

Value of Inverted Engines.—An inverted engine when used in airplanes, possesses four major advantages. First, in the usual type of single-engine tractor airplane, the pilot's vision straight ahead is seriously obscured by the cylinders and cowling of either a V-type or a large radial-type engine. He is practically compelled to swing the airplane from its true course to obtain a view along the normal line of flight. It is unthinkable that poor vision dead-ahead, such as this, will be tolerated when the air is as full of airplanes as we expect it to be in the future. Collisions in the air, even today, are far more numerous than would be the case if poor visibility conditions did not exist. With an inverted engine, as shown in Fig. 124 C, the cowling in front of the pilot can be made in slope to meet the line of the propeller-hub, in this way, favorable vision can be secured. The second major advantage of the inverted engine lies in the high center of thrust that ensures better flying qualities, in that it offsets the tendency of the airplane to climb when full power is on. This is also shown in illustration. The additional propeller-tip clearance is also desirable from a consideration of taxying over rough ground and, in some cases, removes the limitation on the diameter of the propeller that would otherwise exist with a direct drive, conventional installation as shown at 124 C and to a lesser degree with a geared drive screw installed in an engine with upright cylinders.

A third point in favor of the inverted engine is its accessibility to a mechanic working on the ground. If the engine mounting is properly designed and the cowling suitably arranged, the engine can be readily worked on from the ground without the necessity for stepladders and other equipment. Furthermore, the crankcase covers can be removed and the bearings examined, should this be desirable.

The fourth point in favor of the inverted engine has regard to the location of the carburetors that, in many installations, will allow gravity fuel-feed and will avoid the use of complicated piping and pumping arrangements. The fire risk is also diminished to a certain extent with this arrangement, for gasoline leaks are confined to the extreme bottom of the installation, and covering the whole exterior of the engine with gasoline,

as is normally the case, is not possible, as any leakage of fuel will drip off to the ground or into suitable catch basins or tanks intended to receive it.

Future Engine Development.—Turning now to possible future developments it may be of interest to speculate toward what direction progress in aircraft engines will lead. Problems to be solved in this field are well known and consist largely of detailed improvements intended to yield lighter and more reliable engines that will be more economical with respect both to first cost and to operation and maintenance. Although much experimental effort in engine development is being continually directed along unconventional lines, such as the barrel and cam types, and engines employing the Diesel or semi-Deisel cycle, it is reasonable to believe that during the next few years important advances will be made by conventional 12-cylinder water-cooled engines and by 9-cylinder fixed-radial air-cooled engines, the two types that offer the best possibilities for immediate engineering advance and where very high powers are required from a single motor the X form of 24 cylinders, the W form of 18 cylinders and the double banked nine-cylinder or 18-cylinder radial air-cooled engines are all possibilities that have already been realized in experimental types.

It is reasonable to look forward to having available in the near future engines that will weigh about 1 pound per horsepower; and, concurrently with this development, considerable effort will undoubtedly be devoted toward reducing the specific fuel-consumption. For it should be borne in mind that an engine weighing 1 pound per horsepower will, at the present rate of fuel-consumption, consume its own weight of fuel every 2 hours. Doped fuels and higher compressions will make possible higher power outputs for a given cylinder displacement. Ethyl-gas is said to permit the use of pressures up to 150 pounds per square inch before ignition without risk of premature ignition or detonation after ignition. The compression limit with aviation gasoline is about 110 to 120 pounds, so a 25 per cent increase in mean effective pressure is possible without changing engine designs other than augmenting the compression and increasing strength of parts to withstand augmented stresses produced by increased explosion pressures.

The Attendu Solid Injection Oil Engine.—A two-cylinder experimental engine designed by André Attendu, a French engineer and a member of the S. A. E., for the United States Navy is shown at Fig. 125 and tests that have been made to date as reported in the S. A. E. Journal have given very promising results. It was built primarily to determine if a light weight engine could operate at high speeds under the high pressures that prevail in oil engines.

This aviation engine, which is the most recent and advanced engine built by Mr. Attendu is of the high-compression self-ignition type. It operates on the two-stroke cycle, using solid, that is, airless, injection and can be started from cold on its normal fuel, which is 0.93-specific-gravity fuel-oil. The engine is extremely flexible; it is capable of maintaining a high torque throughout a speed range of from 400 to 1,600 r.p.m. This flexibility is obtained by refinement in the regulation of the fuel pump and by a patented system of compression-pressure control. This engine has

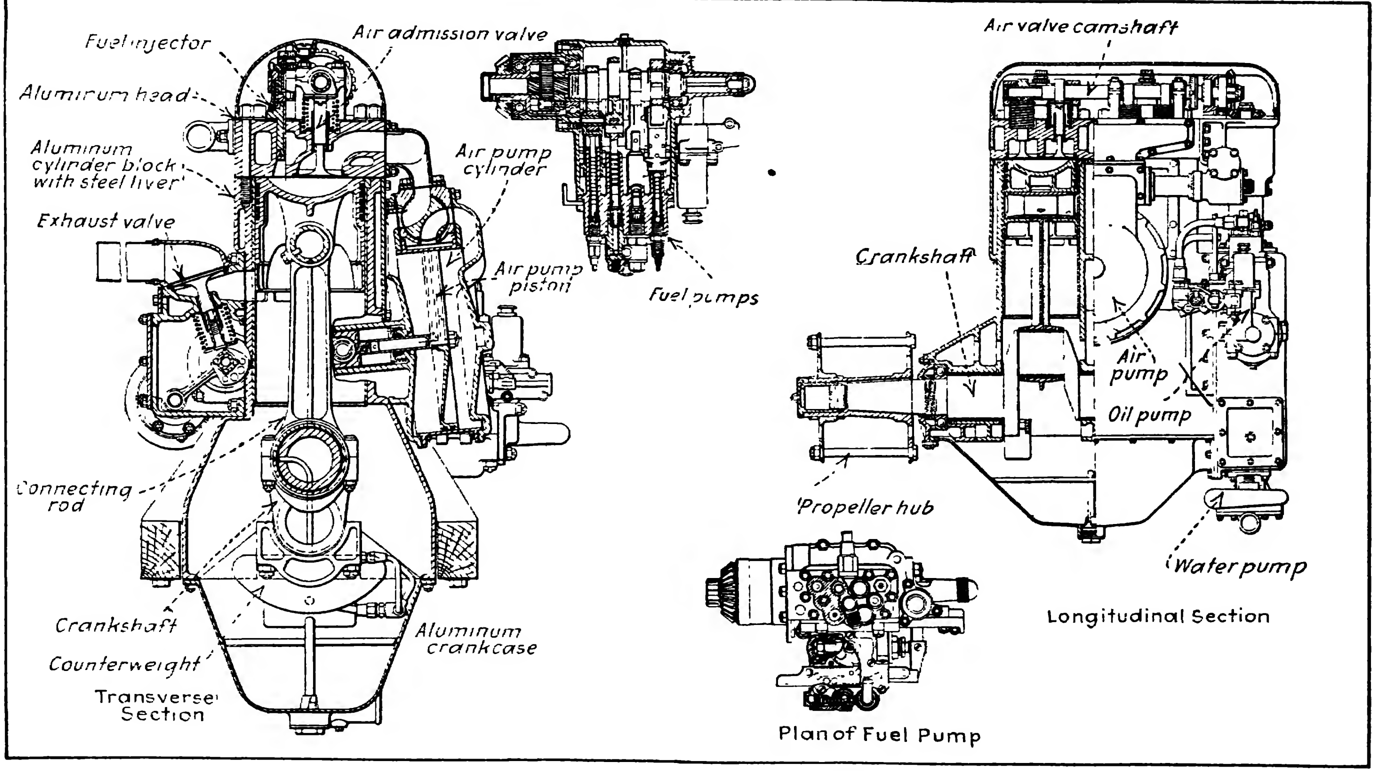


Fig. 125.—Diagrams Showing Construction of Attendu Heavy Oil Aviation Engine Built for U. S. Navy Experimental Work which has a Remarkably Low Weight for this Type.

two cylinders, 5½ x 6½ inches, and a rated output of 100 b.hp. at 1,500 r.p.m. Port scavenging and uni-directional flow of air and gases are obtained by placing the inlet-valves in the head. A large-diameter short-stroke air-pump is mounted at the side of the engine, with its axis nearly horizontal. It is double-acting and is driven at crankshaft speed by a lay-shaft that also operates the exhaust-valves. These valves, two per cylinder, are set in a pocket close to the exhaust ports and their time of closing is governed by an automatic control. The valves are always open when the piston uncovers the exhaust ports, but are closed at a variable point before the ports are covered again. By variation in this point of closing, the effective length of the compression stroke is altered. Thus, in starting and at the lower speeds, a greater volume of air is retained in the cylinder to compensate for the slow compression and consequently greater losses of heat and pressure. Thus the final compression-pressure may be held at a sensibly uniform value. This is an essential feature of the Attendu engine and is shown in the transverse section in Fig. 125.

Elements of the Fuel System.—The fuel-injection system comprises three main elements: (*a*) a primary, or low-pressure, pump; (*b*) a high-pressure pump that meters and injects the fuel and (*c*) a spray nozzle or injection valve.

Both the primary and injection pumps are of the single-acting plunger type and are operated from a common shaft, on which are two primary plungers driven by eccentrics. These supply two injection plungers, one per cylinder, which are cam-operated. The low-pressure stage is required to draw fuel oil from the tank and to ensure the rapid and complete filling of the high-pressure cylinder. Variation in the power output of the engine is obtained by controlling the quantity of fuel injected at each stroke and this is accomplished by lifting or lowering the high-pressure plungers in relation to the cams. This action has the effect of altering the point at which injection commences, but this is automatically compensated for by the timing mechanism of the pump. In addition, a wide range of timing control is available.

The injector consists essentially of a nozzle that is controlled by a spring-loaded needle-valve. This valve is set to retain its seat against the pressure due to the primary stage of the fuel-pump, but opens promptly upon the marked increase in pressure due to the operation of the high-pressure plunger. The timing is arranged so that sensibly constant-volume combustion is obtained at the lower speeds. As the speed is increased the cycle changes from constant-volume to constant-pressure cycle.

The engine was delivered in February, 1925, and ran fairly well up to 1,800 r.p.m., but lubrication and minor mechanical troubles developed in the valve adjustment, couplings and elsewhere, which delayed the official tests until the end of November, 1925, when the first test was passed successfully and the title to the engine vested in the United States Government.

When first delivered, the engine developed 61 b. hp. at 1,350 r.p.m. With improvements on the adjustment and especially on the lubricating-oil system, the brake-horsepower increased to 76 at 1,360 r.p.m., 82 at 1,610 r.p.m., and 85 at 1,620 r.p.m. The best power output, 91 b.hp. at 1,525 r.p.m., was obtained in Mr. Attendu's laboratory and he stated that by making some

other alterations that were in course of execution an additional output of from 20 to 25 b.hp. can be obtained, which will bring the engine up to between 110 and 116 b.hp. for a total weight of 417 pounds, or 3.6 pounds per b.hp. The fuel-consumption is now in the neighborhood of 0.6 pounds per b.hp.-hr., and the expectation is to reduce it to 0.5 pounds. The maximum speed recorded with this engine is 2,210 r.p.m. A very complete description of this engine can be found in the S. A. E. Journal for February, 1926.

Materials Used in Aircraft Engines.—The problem in designing aircraft engines is to obtain the best relation of (*a*) weight, (*b*) frontal area, (*c*) cost, (*d*) bulk, (*e*) high performance, and (*f*) reliability; and all of these factors are involved with the proper arrangement of parts and the proper selection of materials. More than 40 different kinds of material are used in the modern engine, of which the more interesting are the light and unusual alloys, such as magnesium, aluminum-bronze, duralumin, and Y alloy. For example, it has been stated that fourteen different materials are used in one cylinder-block of the Curtiss 500-hp. engine, as follows: duralumin, magnesium, aluminum-bronze, nickel-chromium steel in two analyses, carbon-steel in two analyses, cast iron, brass, copper, cold-rolled steel, drill rod, chrome-vanadium steel, and silchrome steel. The tables that follows showing "Strength-Weight Ratio of Various Materials" and "Properties of Aluminum Alloys" were furnished by the Wright Aeronautical Corporation, Paterson, New Jersey.

TABLE XVI

Table Showing Strength-Weight Ratio of Various Materials

Material	Weight lb. cu. in.	Ultimate Strength lb. sq. in.	Strength Weight x 1000
Steel, mild	.282	60,000	213.
Steel, alloy, heat treated	.282	175,000	620.
Duralumin, forged and heat treated	.101	60,000	594.
Cast Aluminum, 8% copper	.11	16,000	146.
Cast Aluminum, high strength, heat treated alloys	.11	35,000	318.
Magnesium Alloy— 96% magnesium 3% aluminum 1% zinc	.064	18,000	280.

Future Developments.—Future development of the water-cooled aircraft engine in the opinion of Arthur Nutt, M. S. A. E., probably will be the combination of reduction gearing from the crankshaft to the propeller with high engine-speed and supercharging. The gear-reduction problem has been solved and gears can now be made as reliable as the engine. Availability of the lighter alloys at reasonable cost, together with supercharging and gear reduction, make possible the reduction of the engine weight to close to 1 pound per horsepower. During the last 10 years the weight of water-cooled engines has been reduced from more than 4.00 pounds to less than 1.33 pounds per horsepower, dry weight.

TABLE XVII

Properties of Aluminum Alloys Used for Aircraft Engine Construction

Name of Alloy	Approximate Chemical Composition %	Heat Treatment	Average Physical Properties			Remarks
			Tensile Strength lb. sq. in.	Elongation %	Brinell Hardness No.	
8% Copper Alloy W. A. C. NF-104	Copper 8.0 Impurities 1.7 max. Aluminum remainder	Anneal	14,000 to 18,000	5	55 to 60	Used for general casting purposes.
Silicon Alloy (Developed by U. S. Air Service)	Copper 3.0 Silicon 4.0 Impurities 2.0 max. Aluminum remainder	Anneal	20,000 to 23,000	2.0 to 3.0	55 to 65	Easy to cast and free from casting defects. Does not machine freely.
Lynite No. 195 W. A. C. NF-130	Copper 5.0 Manganese .1 Silicon .65 Impurities 1.0 max. Aluminum remainder	36 hrs. at 975° F. Quench cold water	25,000 to 35,000	8.0	50 to 65	Used for highly stressed parts not subject to heat.
Duralumin (Forged)	Copper 4.0 Manganese .7 Magnesium .5 Impurities 1.0 max. Aluminum remainder	Varies with manufacturer	55,000 to 60,000	17.0	100	For parts subject to high stresses and shock loading which can be made by forging or rolling.
"Magnalite" or "Y" Alloy W. A. C. NF-125	Copper 5.5 Magnesium 1.5 Nickel 2.25 Impurities 2.0 max. Aluminum remainder	3 hrs. at 950° F. Quench boiling water. Age 16 hrs. at 300° F.	25,000 to 40,000	.5 to 3.0	90 to 110	A high strength cast and heat treated alloy. Used for cylinders, pistons, etc.
Al-Cu-Fe-Mg Lunite No. 122	Copper 10.0 Iron 1.25 Magnesium .25 Impurities 1.0 max. Aluminum remainder	5 hrs. at 925° F. Quench boiling water. Age 16 hrs. at 300° F.	30,000 to 40,000	.... 1.0	90 to 110	Used principally for pistons.
Magnesium Alloy	Magnesium 96% Aluminum 3% Zinc 1%	None	19,000	6.0	45	Experimental.

A marked increase in the brake mean effective pressure of aircraft engines during the war period was due principally to improvement in spark-plugs. The compression-ratio is limited by the detonation characteristics of the available fuel; the highest ratio that is regarded as advisable when using domestic aviation-gasoline is 5.5 to 1.0. No radical increase in engine-power with present designs is to be expected except as the result of raising the normal engine-speed or of the use of non-detonating fuel. By the use of superchargers it is expected that the mean effective pressure can be kept at about 140 pounds per square inch at the higher engine-speeds, which will mean a tremendous output of power from a small engine. However, the effect of the use of tetra-ethyl lead in fuel in permitting higher compressions as well as the use of a supercharger offers interesting possibilities for future development as this will reduce fuel-consumption from the present figure by greatly increasing the power output possible from a given cubic capacity of the engine, which means an increase in volumetric efficiency.

Airplane Engine Costs.—The reader who has priced airplane engines which are offered by the builders may think such engines are greatly over-priced if he bases his conclusions on cost of automobiles, for example. Airplane engine output is limited because the demand is limited and much of the high cost can be attributed to the high cost of production inevitable when engines are produced in small quantities. As the demand increases and the production augments the prices will become lower. Airplane engines, especially the types built for military purposes will never be cheap because of the nature of the materials used and the expensive machining and inspection processes will make a relatively high cost imperative, no matter how many engines are built. Commercial engines, however, will become cheaper as output increases.

In comparing airplane and automobile engines, the latter need an overhauling after 20,000 miles travel and seldom run more than 50,000 miles as that figure represents from seven to eight years normal service. The automobile engine is operating at less than capacity over 90 per cent of the time it is in use, most of the time it is being run at about 25 per cent of its power. An airplane engine is usually operated in the range from 75 to 100 per cent of its power. It is so highly refined at the present day that it may run as many miles at open throttle and full power output as an automobile engine does at quarter throttle. Air-cooled aviation engines have run 300 hours without an overhaul, which corresponds to 30,000 miles service if we assume a speed of 100 miles per hour. There is no automobile engine built that could run even a tenth of this mileage at wide open throttle without requiring overhauling. After overhauling, an airplane engine returns to service and some modern engines are capable of undergoing four overhauls and running for periods ranging from 800 to 1,000 hours without wearing out, or 80,000 to 100,000 miles service at practically its full power output or at least, three-quarters of its full capacity.

Figures taken by considering various forms of stationary gasoline engines show a price range of from $10 to $20 per horsepower. Diesel and kerosene burning engines may cost as much as $60 per horsepower. A good steam engine costs $25 to $30 per horsepower for the engine alone

and it is useless without expensive auxilaries such as boilers, pumps, condensers, etc., that will bring the cost of the complete installation much higher. Motor boat engines sell for from $20 to $30 per horsepower. Outboard motors may cost as high as $70 per horsepower for a small engine to $35 per horsepower for a five to six horsepower size. Automobile engines cost from $30 to $40 per horsepower and are not capable of maintaining their full power output nearly as long without trouble as even the poorest of the relatively early types of aviation engines. Few stock or even racing automobile engines could go through the 50 hour test at full throttle that airplane engines must pass.

The writer was recently quoted a price of $1,200 on an aviation engine rated at 80 horsepower at 2,200 r.p.m., and this was not a wartime left-over but a new, recently developed small radial air-cooled engine. This brings the cost to $15.00 per horsepower. An analysis of costs of aviation engines by an aeronautical magazine Aviation made recently gave an average value of $20 per horsepower for aircraft engines so if one compares the cost with that of other engines in performance or endurance, one will concede that such engines are not unduly expensive.

Engine Starting Methods.—Various forms of starter have been tried for years with but indifferent results and, so long as the engines were small and were capable of being cranked by hand by pulling through the propeller, starters were not received with much favor. Pulling through the propeller by hand is a dangerous operation at best and even a skilled mechanic of good physique cannot turn the engine past more than one or two compression points, except in the case of small engines having no military and very little commercial value. Electric starters have been devised which employ a small motor, driving through a large gear-reduction. The early forms of these starters gave trouble and they were very hard on batteries; also, the battery capacity required entailed the use of large and correspondingly heavy batteries. Therefore, for many years after the World War, engines up to and including the 200-hp. size were started by pulling the propellers when the propeller was accessible. For larger engines and for seaplane work, small hand-starters were used which consisted solely of a hand-crank geared down to the crankshaft.

Compressed-air starters of various types came into extensive use on European engines and were used to some extent on early American engines. These starters consisted of a supply of compressed air stored usually in a small steel bottle that was carried on the airplane, a miniature carburetor in the air-supply line, a distributor driven from a camshaft, and individual pipes leading to check-valves installed in the cylinders. These compressed-air starters have been very efficient so far as starting is concerned but, in this country, airplane engine builders have been unwilling to accept the multiplicity of piping and valves required and the driving of any unnecessary mechanism from the camshaft.

U. S. Navy Practice.—Starter developments in the United States have taken the form of the inertia starter, said Lieutenant C. E. Champion, Jr., U. S. N., in a paper read before the Buffalo Section, S. A. E. recently. These are being built for the Navy at present by the Healy-Aeromarine Bus Co., successor to the Aeromarine Plane & Motor Co., and by the

Eclipse Machine Co., in its plant at Hoboken, N. J. These starters employ a hand-crank and a gear-train which drives a miniature flywheel, and a constant-torque slipping-clutch through which the flywheel can transmit its energy to the engine. In operation, the crank is turned by hand until the flywheel is brought up to the required number of revolutions per minute. A man of normal physique should accomplish this in 20 to 30 seconds. The gear-reduction is approximately 150 to 1 and the weight of the flywheel is about 4 pounds. When the flywheel has been brought up to about 15,000 r.p.m., a tripping device connects the flywheel, through the same gear-train used to drive it, to the constant-torque clutch and, at the same time, engages the starting-dog. At average operating-speeds, the energy stored-up in the flywheel amounts to 5,000 foot-pounds or more. The clutch can be set for any desired break-away torque. In small engines, a torque of 400 foot-pounds suffices but, for the largest engines, clutches are set for 750 foot pounds.

By careful arrangement of the gear-train, these starters have been reduced in size to that of the crown of a man's hat and their total weight is between 19 and 25 pounds depending on the model. They are very rugged and reliable. Incidentally, it is indicated that their use will eliminate the necessity for the hand-operated booster-magneto used for starting purposes, which will result in a saving of some 11 or 12 pounds in weight. Various forms of engine starters will be considered more in detail in Chapter 10 to follow.

Engine Terms

Types of Engines

barrel-type engine—An engine having its cylinders arranged equidistant from and parallel to the main shaft.

inverted engine—An engine having its cylinders below the crankshaft.

left-hand engine—An engine whose propeller shaft, to an observer facing the propeller from the antipropeller end of the shaft, rotates in a counterclockwise direction.

left side (engine)—That side which, to an observer looking from the antipropeller end toward the propeller end, lied on the left-hand side.

radial engine—An engine having stationary cylinders arranged radially around a common crankshaft.

right-hand engine—An engine whose propeller shaft, to an observer facing the propeller from the antipropeller end of the shaft, rotates in a clockwise direction.

right side (engine)—That side which, to an observer looking from the antipropeller end toward the propeller end, lies on the right-hand side.

rotary engine—An engine having cylinders arranged radially with crankcase and cylinder assembly revolving around a common fixed crankshaft.

supercharged engine—An engine with mechanical means for increasing the cylinder charge beyond that normally taken in at the existing atmospheric pressure and temperature.

vertical engine—An engine having its cylinders arranged vertically above the crankshaft.

V-type engine—An engine having its cylinders arranged in two rows, forming, in the end view, the letter "V."

W-type engine—An engine having its cylinders arranged in three rows, forming, in the end view the letter "W." Sometimes called the "broad-arrow type."

Superchargers

supercharger—A mechanical device for supplying the engine with a greater weight of charge than would normally be induced at the prevailing atmospheric pressure and temperature.

centrifugal type—A supercharging device equipped with one or more rotating impellers generating centrifugal force which is utilized for the compression and the transmission of the air against resistance.

positive-driven type—A supercharger driven at a fixed speed ratio from the engine shaft by gears or other positive means.

rotary-blower type—A supercharging device comprising one or more relatively slow-speed rotors revolving in a stationary case in such a way as to provide a positive displacement.

turbo type—A supercharger driven by a turbine operated by the exhaust gases from the engine.

Miscellaneous Terms

brake mean effective pressure—The net unit pressure which, if applied during the power strokes to the pistons of an engine having no mechanical losses, would produce the given brake horsepower at the stated speed.

dry weight of an engine—The weight of the engine, including carburetor and ignition systems complete, propeller hub assembly, reduction gears, if any, but excluding exhaust manifolds, oil and water. If the starter is built into the engine as an integral part of the structure, its weight shall be included.

fixed power plant weight for a given airplane.—The weight of the engine, including ignition, carburetor and induction systems complete, propeller and hub, exhaust manifolds, radiator and water, *if used*, with all interconnecting wires, controls, tanks, and pipes, lubricating oil temperature regulators, *the oil contained in the engine crank case*, and the starting gear attached to the engine, but excluding fuel, oil, and engine instruments.

maximum horsepower of an engine—The maximum horsepower which an engine can develop.

maximum revolutions—The number of revolutions per minute corresponding to the maximum horsepower.

rated horsepower of an engine—The average horsepower developed by an engine of a given type in passing the standard 50-hour endurance test.

rated revolutions—The number of revolutions corresponding to the rated horsepower.

specific fuel (or oil) consumption—The weight of fuel (or oil) consumed per brake horsepower-hour.

weight per horsepower—The dry weight of an engine divided by the rated horsepower.

QUESTIONS FOR REVIEW

1. Name essential requirements of aerial motors.
2. Describe briefly the main factors determining amount of power needed.
3. What is the difference between an air-cooled engine and one cooled by water?
4. What system of engine cooling do you think best for airplane engines and why?
5. Describe parts contributing to power plant weight and which type of engine is lightest.
6. Name principal airplane engine forms.
7. Why is it better to use multiple engine planes for passenger carrying and in commercial use than single engine types?
8. How are engines installed when three engines are used?
9. Why is radiator location important when water cooled engines are used for power?
10. What is an inverted engine and what are its advantages?

CHAPTER VIII

AVIATION ENGINE DESIGN AND CONSTRUCTION—AIR-COOLED ENGINES

General Considerations of Air-Cooling—Air-Cooling not Restricted to Radial Engines—Reason for Radial Cylinder Disposition—Air-Cooled Cylinder Design—Cooling Exhaust Valves—Arrangement of Cooling Fins—Table XVIII, Factors of Safety, Air-Cooled Cylinder Parts—Material for Air-Cooled Cylinders—Small Air-Cooled Engines—Wright-Morehouse Two-Cylinder Engine—The Bristol "Cherub" Engine—The Wright "Gale" L4 Engine—Meteormotor Radial Engine, Four Cylinder—Fairchild-Caminez Engine—Detroit Aircraft Engine, Five Cylinder—Super Rhone Nine Cylinder Engine—Wright "Whirlwind" J4A Engine—Wright J4B and J5 Engines—Pratt and Whitney "Wasp" Engine.

General Considerations of Air-Cooling.—Air-cooling is accomplished by causing the air from the propeller slipstream to strike the cylinders laterally at right angles to the cylinder axes, which involves circumferential finning. This makes the cylinders easy to cast and to machine, furnishes strength against internal pressure and allows the maximum cooling-surface on the ports and on the combustion-chamber. The material used must have a high rate of heat transfer from the surface to the air so aluminum alloy heads with integrally cast fins have been used for the purpose, being shrunk on, threaded on or cast on an iron or steel cylinder sleeve.

The thermodynamics of air-cooled-engine design appear to be as sound as those of water-cooled engines, and the troubles encountered have been largely mechanical. Nothing inherent exists in the air-cooled engine to make it less durable or dependable than the water-cooled engine. It is less sensitive to sudden heat or cold, is easier to start and requires less warming-up in cold weather, the last feature being very desirable in the alert type of airplane. It is not subject to boiling-over when climbing steeply in hot weather or when operating in tropical climates. The oil never heats unduly and always remains at working temperatures.

Top overhauls are easier to make. The grinding of valves involves only the removal of a cylinder and the touching-up of the valves, with no change in timing. Water-cooled engines, as a rule, require either the removal of the engine or the dismantling of the camshafts and valve mechanism, and that the entire engine be retimed upon reassembly. The ability to effect quick repairs is a decided advantage. Due to the reduction in the number of parts, the radial air-cooled engine usually can be built more cheaply than can the water-cooled engine, with its complicated auxiliaries and piping, and lends itself better to quantity production. The tendency in water-cooled engines is toward block construction to give a more rigid and a lighter structure. This involves the rejection of an entire block for the defect of a single cylinder, a condition not encountered in radial engines.

Air-Cooling Not Restricted to Radial Engines.—It is well to point out here that air-cooled engines in aviation are not restricted to fixed-radial

and to rotary types. A Liberty-12 engine has been successfully air-cooled by the Army Air Service at McCook Field, Dayton, Ohio. This engine developed slightly more than its rated horsepower as a water-cooled engine. It had a tendency to over-cool rather than to under-cool. The change from water-cooling to air-cooling consisted primarily in the substitution of air-cooled cylinders for the regular ones and the interchanging of the exhaust and the inlet-valves. In general, in earlier types of air-cooled engines, the higher temperatures of air-cooled cylinders have resulted in lower brake mean-effective pressures and economy for high powers, and high rotative-speeds in static radial-engines have been limited by the so-called connecting-rod "big-end" conditions but in latest types, both of these limiting factors have been improved so the performance compares well with water-cooled engines.

The term "brake mean-effective pressure" means the average effective pressure that, if applied to the piston in each cylinder, will produce the given horsepower. It is not expected that the next few years will witness anything revolutionary in design, although steady improvement is going on in closer thermal-contact between steel cylinder-liners and aluminum heads, more careful valve seat cooling, proper combustion chamber form, better carburetion, and more advantageous spark plug location.

Reason for Radial Cylinder Disposition.—Engine size for a given power depends both upon mechanical and thermal efficiency. With higher crankshaft-speeds and more accessories, especially engine-driven superchargers, friction horsepower becomes particularly important. This item remains practically constant and therefore affects the mechanical efficiency most seriously at high altitudes. It is equally important to obtain the maximum mean-effective pressure from a given cylinder to get the best over-all efficiency. Extremes in speed and compression-ratio are sometimes resorted to in order to produce the required power output, instead of providing proper means of filling each cylinder with the maximum-weight charge at a more normal speed. A question often asked is, Why does the air-cooled aeronautic engine take the radial form? The reason is, that more uniform cooling can readily be secured for each cylinder than with any other type. Originally it was felt that it was necessary to add to the cooling obtained from this disposition of cylinders by rotating the cylinders around the crankshaft. Such engines were called rotary engines and include the Gnome, Clerget and Le Rhone. This type has been discarded because the rotative speed, and consequently the maximum power of any given engine, was limited by centrifugal force and also because the engine consumed power just to turn the cylinders against the air resistance, this loss being as high as 15 per cent of the total output.

It is probable that the radial type will be used for aircraft engines up to 500 horsepower at least. Two or more rows of radial cylinders back to back are possible, but are not considered especially promising, on account of the less effective cooling and the added complications, especially of the valve-gear. Wherever more than 500 horsepower is required, it is probable that the single V or double V-type known as the X, engine will be used. The Royal Aircraft Factory has already shown this type to be entirely feasible and, in this country, the Engineering Division of the Army

Air Corps has converted a 400-hp. water-cooled Liberty engine into an air-cooled engine.

With the V-type, it is necessary to provide cowling to direct the air-flow to the cylinders; it is not necessary to use a blower for this purpose though the early Renault air-cooled engine used a blower for the air blast. Engines of this type are not apt to be lighter per horsepower than the radial type even though counterweights are eliminated. The higher crankshaft-speed possible by the elimination of the master-rod, and therefore the higher power, is counteracted by the added weight of the long crankcase and shaft required by the cylinder spacing. Because of the addition of cowling as well as the increased number of cylinders, the V-type is not so accessible nor so readily dismantled as are radial engines, which are inherently simple from a maintenance standpoint.

Heretofore, the drag of the cylinders was supposed to have been considerably greater than that of the radiator usually required for a water-cooled engine. This assumption has been disproved, as similar airplanes equipped with both air and water-cooled engines have shown a considerable increase in speed in favor of the air-cooled type, as has previously been brought out. This increase is particularly noticeable at high altitudes when the ordinary radiator is shuttered. High speed is possible with the radial type of engine, as shown by the Gourdon airplane, which is reported to have reached a maximum speed of 224 m.p.h. with a 450-hp. radial engine.

Air-Cooled Cylinder Design.—The power output for a given size and speed is controlled largely by combustion chamber design, size of valves, size and shape of ports, and cooling of the cylinder. It has been the experience of nearly all experimenters that the nearer one can approach to a spherical combustion chamber, the better will be the results obtained.

One of the most important considerations in securing maximum power output is the size and shape of the intake and exhaust ports. The internal shape of the ports must be such as to offer the minimum resistance to the flow of the gases in and out of the cylinders, while their external shape must be such as to accommodate reasonable forms of intake and exhaust manifolds, and to offer the least possible interference to the flow of the cooling air around the cylinder head. In order to offer the least possible restriction to gas flow, the passages within the ports must have easy bends with plenty of area at the bends, especially around the valve guide bosses. Rapid changes of section must be avoided, and the area of any section of the passage must always be as great as, or greater than, the clear area of the valve opening. Of the two forms of combustion heads shown at Fig. 126; C. F. Taylor of the Wright Aeronautical Corporation is the authority for the statement that the form at B is superior to that shown at A. The spherical form of combustion chamber is followed, easier gas flow in or out is obtained, the valve is a tulip head, salt cooled stem type, the stem guide is clamped in instead of forced in and better flanging is evident.

Perhaps the most difficult problem in air-cooled cylinder design is to secure proper cooling. In considering this problem, two principles must be kept in mind, namely:

(1) The parts which receive the most heat are the parts which require the most cooling air.

(2) The blast of cooling air must impinge as directly as possible on the parts to be cooled, with a minimum dependence upon the conduction of heat through the metal or joints.

The parts which receive the most heat during engine operation are the exhaust valve, exhaust port, combustion chamber and cylinder barrel.

Cooling Exhaust Valves.—In considering the cooling of the exhaust valve, it is obviously difficult to apply the second principle, since the valve is largely covered up by the valve seat, port, guide and spring, and even the air which might otherwise get through the valve spring to the upper end of the valve stem is cut off when an enclosed type of valve gear is used.

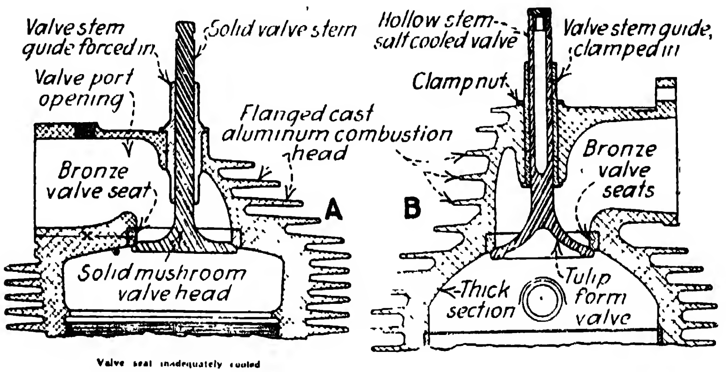


Fig. 126.—Air-Cooled Cylinder Combustion Head Forms. A—Valve Seat Inadequately Cooled. B—Raised Valve Seat a Superior Form. Note Hollow Stem Valve for Salt-Cooling.

Consequently, in this case it is necessary to depend on the transfer of heat to the cylinder through the valve seat and valve guide. The proper cooling of the exhaust valve is therefore largely a question of providing ample area for the transfer of heat to the valve seat and valve guide, and then providing for the best possible air cooling of these parts. This involves some very careful design, and is a problem on which a great deal of study and experimenting has been done. The form shown at Fig. 126 B is superior to that shown at A, especially where enclosed valve gear is used.

Arrangement of Cooling Fins.—The arrangement of fins on an air-cooled cylinder depends primarily on the position of the cylinder with respect to their air blast produced by the propeller slipstream. For aeronautical work, it is now universal practice to arrange the cylinder so that the air blast is directed against the side of the cylinder at approximately right angles to the cylinder axis. When this is the case, some type of circumferential finning is required. Circumferential finning has the following advantages as compared with finning parallel to the cylinder axis.

(a) Adds greatly to the strength of the cylinder to withstand internal pressure.

(b) Is easily machined where machining is necessary.
(c) Is much easier to cast than the axial finning.
(d) Gives more cooling surface on the ports and combustion chamber.

The question of the proper size and spacing of the fins is one which has received a great deal of attention and has been the subject of a number of extensive research programs. The size and spacing of fins is largely controlled by the conductivity of the material used. However, for most materials, the scientifically correct finning calls for fins spaced so closely together and of such thin section that the manufacturing difficulties become prohibitive. Another consideration is that the fins must be sufficiently thick and strong to avoid damage in handling.

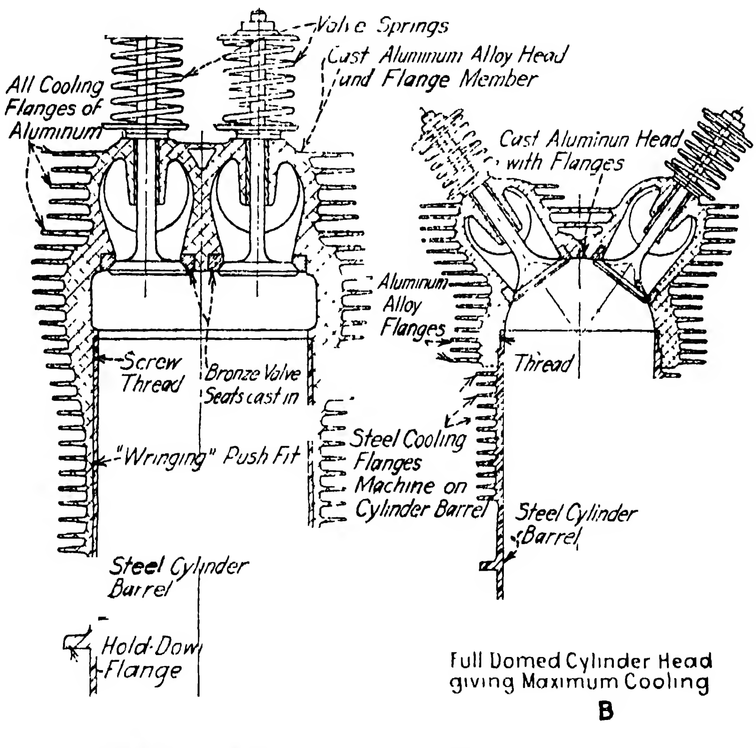


Fig. 127.—Air-Cooled Cylinders for Aviation Engines. A—Steel Barrel Screwed into Cylinder Head of Aluminum Alloy with Integrally Cast Cooling Flanges Extending Down the Cylinder, which is a Force Fit in Surrounding Aluminum Piece. B—Steel Cylinder Barrel with Circumferential Flanges Machined Integral with Short Aluminum Alloy Head Screwed to it. Form B Gives Best Cooling.

Cooling Fin Dimensions.—The finning to be used, therefore, is the result of a compromise between these factors. It has been found that for aluminum or cast iron cylinders, a very good design from all points of view is to make the fins 1 inch long with a thickness of $\frac{1}{8}$ of an inch at the root and 1/16 of an inch at the tip, with a spacing of $\frac{3}{8}$ of an inch between fins. For steel, the fins may be half as thick and spaced as closely as $\frac{1}{4}$ of an inch. The fin spacing is usually increased where the finning inter-

sects the valve ports, as otherwise the manufacturing problem becomes difficult. Two forms of cylinders are shown at Fig. 127, that at A having all flanges of aluminum alloy, that at B having some of the flanges machined from the steel cylinder barrel that is screwed into the alloy head casting. The tabulation Number 18 gives desirable factors of safety.

TABLE XVIII

Factors of Safety, Air-cooled Cylinder Parts

Part	Material	Direct Stresses	Other Considerations	Recommended Factor of Safety Based on Ultimate Strength at Room Temperature
Cylinder Barrel at thinnest section	Steel	Tension due to pressure on cylinder head	Rapidly varying load Vibration Fairly high temperature	
Hold down studs (Root diameter)	Steel	Tension due to pressure on cylinder head	Rapidly varying load Severe handling stresses	12
Sides of combustion chamber at thinnest section	Aluminum Alloy	Tension due to pressure on cylinder head	Rapidly varying load High temperature	10

Material for Air-Cooled Cylinders.—Considering the material of the cylinder from the point of view of cooling alone, we require:

(1) A material having a high rate of heat transfer from its surface to air.

(2) A material having rapid internal conductivity, so that the heat will flow readily from the hotter to the cooler parts of the cylinder, thus avoiding local overheating.

No definite data on the rate of heat transfer to air is available, but from experience it appears that copper, aluminum, steel and cast iron possess this property to a high degree.

Of the metals having high heat conductivity, aluminum alloy stands preeminent on account of its added advantage of light weight, although copper and its alloys have been proposed and used. Copper transmits heat best, then comes aluminum alloy, then cast iron and steel. The question of cylinder materials, however, is largely governed by considerations other than those of cooling, the important one being the resistance to wearing due to piston reciprocation.

Cast iron will fulfil all of the functions in a fairly satisfactory manner, but its weight is generally prohibitive for military engines. For commercial engines cast iron cylinders may often be used to advantage. Cast aluminum alloy is satisfactory as a containing member and can be cast in intricate shapes. It will also stand a fair degree of stressing, and is a fairly good bearing material. However, where high localized stresses are encountered, cast aluminum alloys are liable to failure by fatigue, and consequently have been found unsatisfactory for the hold-down flange, where the cylinder is bolted to the crankcase, unless very heavy sections are used.

In order to overcome these difficulties, a combination of materials has usually been resorted to. Steel makes an excellent bearing surface for the

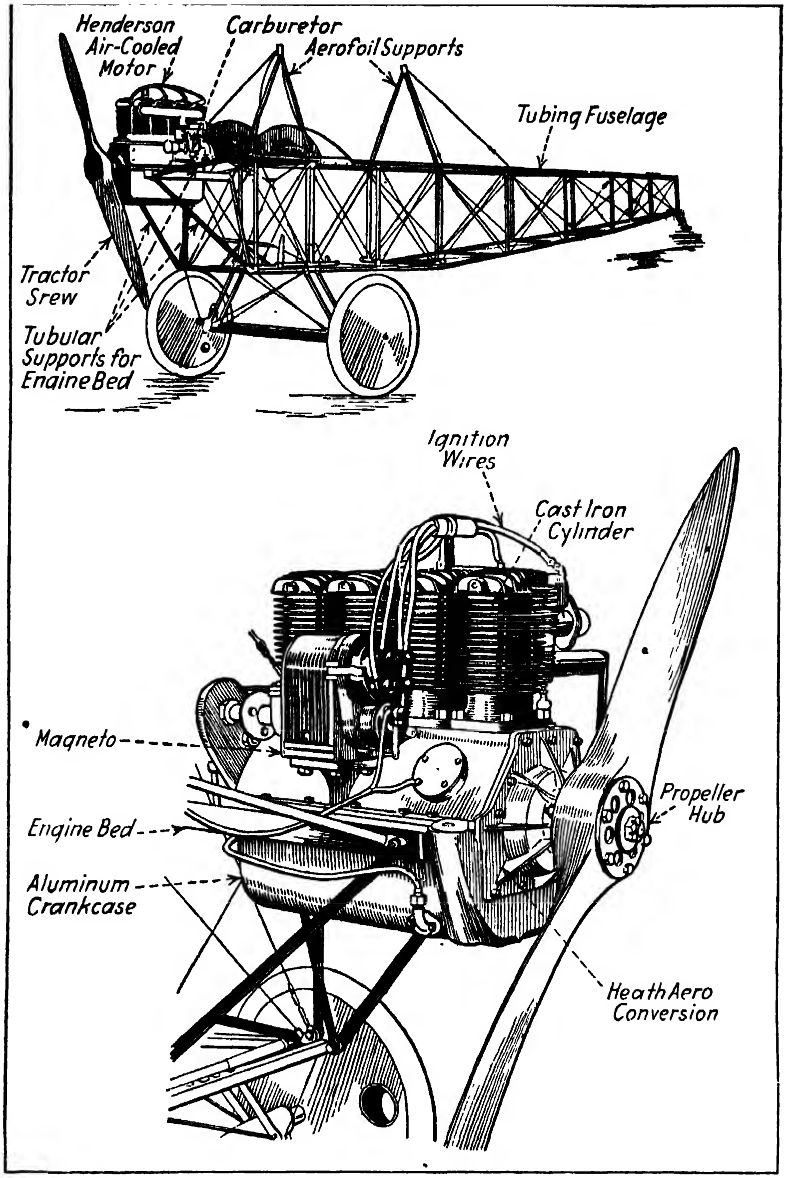


Fig. 128.—How Henderson Motorcycle Engine with Special Conversion is Installed in Heath Parasol Monoplane. Top View Shows Complete Fuselage and Relation of Engine Supports to Other Parts of the Tubular Structure. Lower View is a Close-Up of the Engine, the Small Size of which can be Understood by Comparing it with the Magneto.

piston, and is also the best material available for resisting fatigue and localized stresses such as are encountered at the hold-down flange of the cylinder. It is now almost universal practice in aeronautical work to make air-cooled cylinders with an aluminum alloy head and a steel barrel with hold-down flange. The cooling fins on the barrel may either be machined

integral with the steel as shown in Fig. 126 B, or may be cast with the aluminum head as shown in Fig. 126 A, the steel barrel being made a very tight fit in the aluminum sleeve, which is part of the head casting and machined or bored out to receive it for the greater portion of its length, except where it is threaded to fit corresponding threads on the steel sleeve.

Small Air-Cooled Engines.—The experimenter with small and light airplanes has been somewhat handicapped in the past because of the lack of a simple, efficient and economical engine of small capacity and converted motorcycle engines have been used in experimental work. These have not always been satisfactory because they were heavy in proportion to their power output though much superior to any of the small automobile power plants available for the purpose. Most motorcycle engines were deficient in power output and special aircraft engines were too expensive. The Henderson four-cylinder "De Luxe" model motorcycle engine possesses many of the characteristics of a first-class light plane engine, and by evolving a special conversion that allows the propeller to be driven direct from the crankshaft, the Heath Company have made it possible to use this low priced and popular engine successfully in their "Parasol," a light weight sport monoplane. All Henderson motors, furnished as stock equipment on "Parasol," are equipped with high pressure oiling system. They have been run for many hours on the test block and in planes, giving them a severe test, and have been found to stand up remarkably well. Henderson engines were used in many light plane races in the past few years, and have stood the test. They are remarkable little engines that are unusually well suited for use in inexpensive sport planes. It is said they will drive the plane 35 miles on a gallon of gasoline. The Henderson "De Luxe" motor develops 23 hp. at 3,000 r.p m., and weighs complete with propeller only 117 pounds. It is low in upkeep because it uses standard motorcycle engine parts that are obtainable in any part of the country. The engine is so well known as used in motorcycles that a detailed description is not deemed necessary. The accompanying illustration Fig. 128 shows a Henderson motorcycle engine with special Heath propeller and propeller conversion, installed in Heath "Parasol." The engine mounting employed is so simple that the mounting can be completely dismantled by removing only four bolts. This makes it possible to adapt it to different types of engines without great structural changes. A fuel tank of 3.3 gallons capacity is fitted in the center above the wings.

While the Henderson motorcycle engine is ideal for sport use, it is often desirable to use a more powerful engine to obtain greater speed, where the plane is used for exhibition work. Where such superperformance is desired, and where cost is no object, we recommend the Wright-Morehouse engine, developed especially for light plane use. This engine is of the two-cylinder opposed type, air-cooled, and develops 29 hp. at 2,500 r.p.m. It weighs but 89 pounds, and due to its peculiar design it is easily and effectively streamlined when installed in a small plane. The Wright-Morehouse engine has met with great success in recent air races and has proven reliable and efficient.

Wright-Morehouse Engine.—This is a light opposed cylinder type designed especially for light airplanes. It is clearly shown in illustrations at

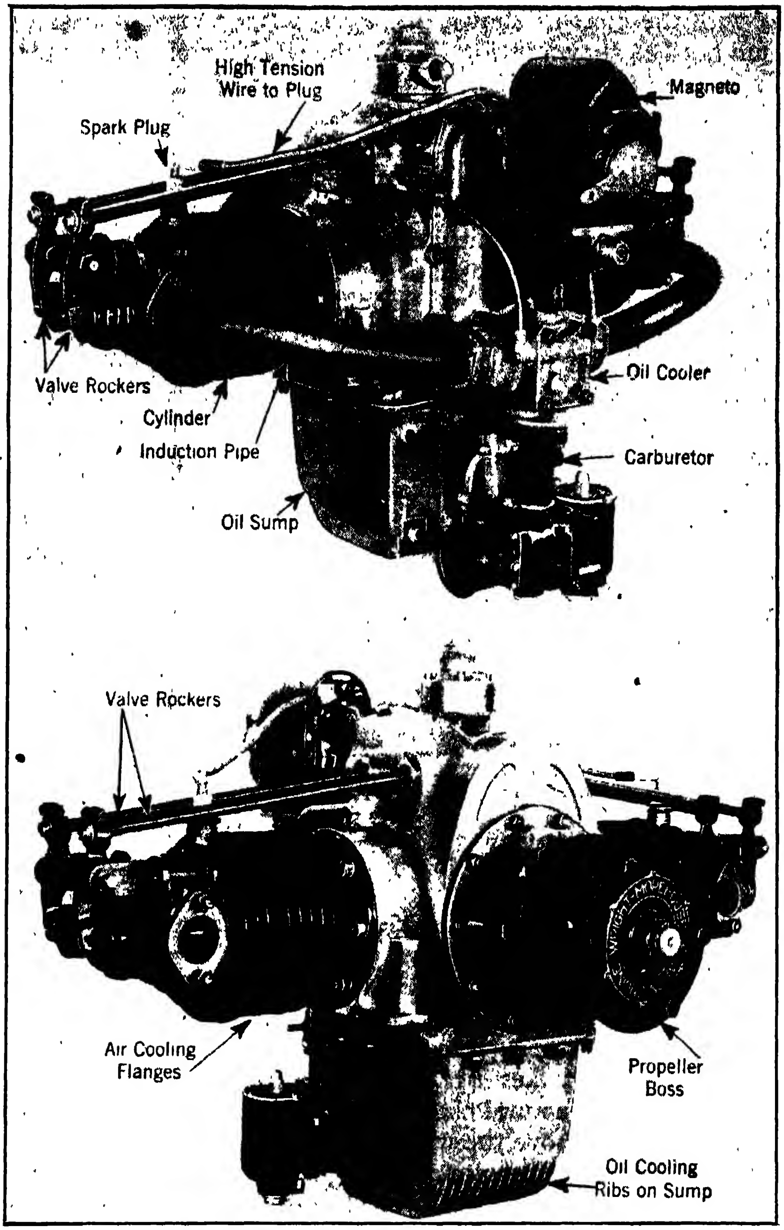


Fig. 129.—The Wright-Morehouse Two Cylinder Aviation Engine. At Top—Rear View Showing Ignition Magneto and Carburetor. At Bottom—Engine Viewed from Propeller End.

Fig. 129 and the sectional engineering drawing at Fig. 130 shows all details clearly for the technical or engineering student. The cylinders are cast iron with integral cooling fins and valve seats. They are attached to the crankcase through the cylinder flange, about half way up the barrel, their location being made by two pilots, one at the flange and one at the end of the barrel. Between these two pilots the crankcase is cored to form

closed passages when the cylinder is in place. Bypass oil from the pump is led into these passage serving to cool the cylinder skirts before returning to the sump. Tulip shaped valves are used, both intake and exhaust having ample diameter and lift. The valve springs are helical and made from special heat treated spring steel wire. Adjustable push rods with ball and socket joints at each end actuate the forged steel rocker arms. Case hardened steel cam followers operate directly on the camshaft. The push rods are so recessed in their sockets that they cannot come out in flight, while the rocker arms are supported on individual forged brackets studded into the cylinder heads.

The crankshaft is a steel drop forging, counterbalanced to reduce vibration, and having two throws at 180 degrees. It is drilled for oil passages, giving pressure lubrication to all bearing surfaces. The camshaft is mounted directly over the crankshaft and parallel to it. The camshaft gear is integral with the shaft and is driven by one idler gear at half engine speed. The idler gear is extended to form the tachometer drive connection. The camshaft and idler gear are both assembled through the rear cover plate. Both crankshaft and camshaft are mounted on large plain bearings of ample size. These bearings are grooved for oil passages to the crankshaft and crankpin bearings. The crankcase is an aluminum casting of especially clean lines.

The connecting rods are of forged duralumin and are of H section. The wristpin bushings are of bronze, shrunk into the connecting rod. The crankpin bearings are babbitt applied directly to the rods. The pistons are the straight cylindrical type, made of aluminum and having crossed ribs supporting the flat piston head. Four rings, three above and one below the piston pin, are used. The hollow piston pins float in both rods and the pistons, bronze end plugs being used to prevent cylinder scoring. The piston pins and cylinder walls are lubricated by oil spray from the crankpin bearings.

A gear pump in the cover plate gives force feed lubrication to the main and connecting rod bearings, idler gear bearing, and camshaft bearings. The sump is equipped with an oil level indicator, oil strainer, and thermometer connection. Cooling fins are cast on the bottom to keep the oil temperature correct. The sump holds about three quarts of oil and is filled through the breather. A single Scintilla magneto, driven direct from the rear end of the camshaft, fires a single plug in each cylinder. An impulse starter coupling between the magneto and the camshaft, insures a quick turn for the magneto in starting. The fuel mixture is supplied by a special carburetor through an oil jacketed elbow attached to the rear cover plate. Individual manifolds carry the mixture to each cylinder. Four holding-down bolts fasten the engine to the bearers. All the controls are at the rear of the engine, thus simplifying the installation in the plane.

SPECIFICATIONS

Bore	3.75 in.
Stroke	3.625 in.
Displacement (1.31 liters)	80 cu. in.
Compression ratio	5 : 1
Rotation	anti-clockwise

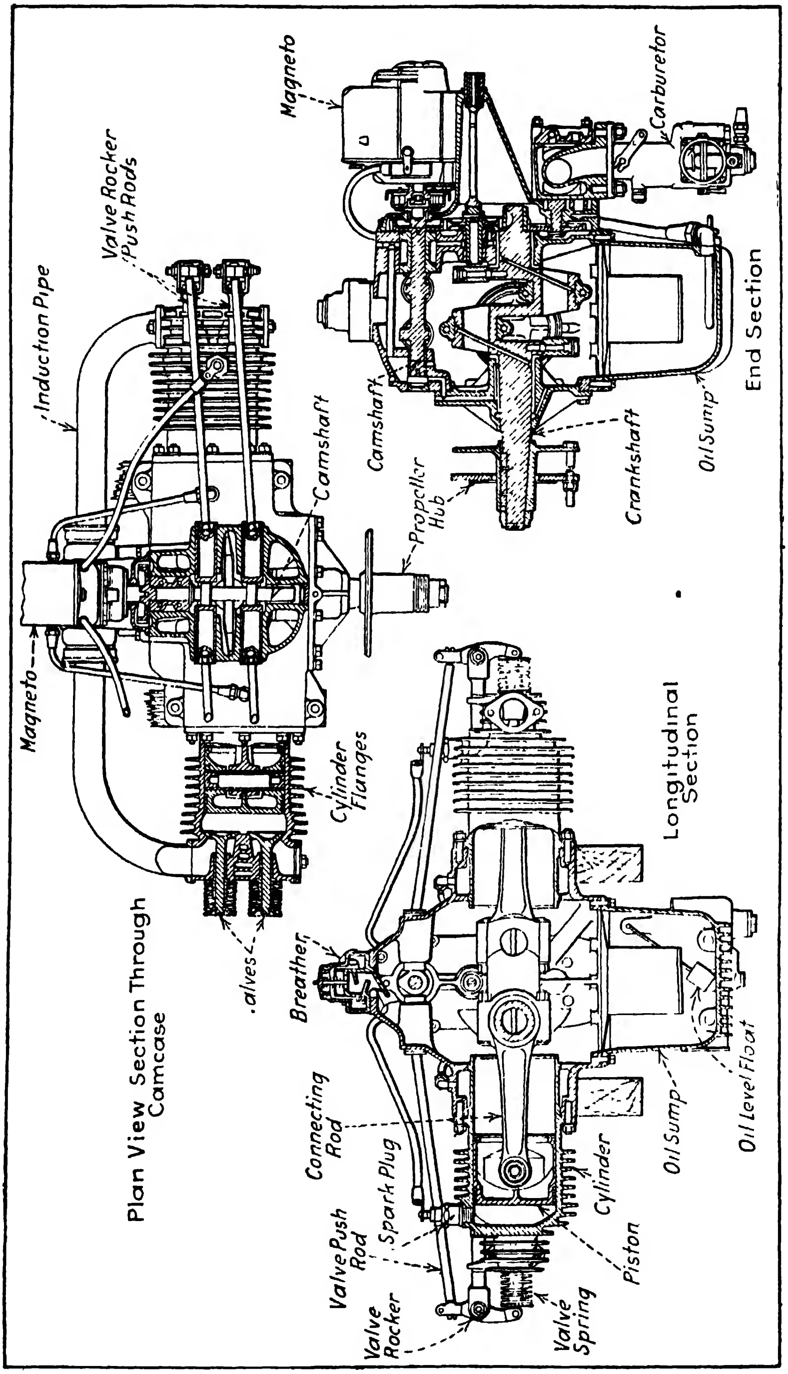


Fig. 130.—Sectional Drawings Showing Construction of Wright-Morehouse Aviation Engine, with all Important Parts Designated for Easy Reference.

Weight, dry	89.5 lb.
Power at 2500 r.p.m.; average	29 hp.
guaranteed	25 hp.
Fuel-consumption at 2500 r.p.m.; average	2.5 gal./hr.
guaranteed	0.55 lb./hp.-hr.
Shipping weight	155 lb.

The Bristol "Cherub" Engine.—This is a very popular engine for light airplanes in England. The engine has recently been submitted successfully to the latest British Air Ministry 100 hour Type tests. It completed this test in ten non-stop periods of 10 hours each, without any hitch, stoppage, adjustments or replacements. On the last hour, the engine held 36.6 b.hp. at 3.200 r.p.m. The average fuel-consumption throughout the test was .586 pints per b.hp. per hour and the average oil consumption .026 pints per b.hp. per hour. At the conclusion of the test, the engine was stripped and found to be generally in excellent condition. The "Bristol" Cherub engine is of the two-cylinder opposed type and has a total swept volume of just under 1,230 cubic centimeters.

The crankshaft is a case hardened alloy steel stamping of ample dimensions, carried in four bearings; the crankcase is an aluminum casting, split vertically on the engine center line and provided with separate front and rear covers.

There are three main bearings. The front one is of the deep groove type, located in the nose of the conical front cover, and transmits the propeller thrust from the crankshaft to the case. The other two are of the double row self aligning type, and situated adjacent to the crank throws, one in front and the other in behind, and are housed in the front and rear half crankcases, respectively. The tail end of the shaft is supported in the rear corner by a plain white metal bearing which provides an oil seal, allowing oil to be supplied through the hollow tail end and drilled oilways to the big end of the bearings. On the shaft between the two rear bearings, a spur wheel and two spiral gear wheels provide drives for the camshaft, tachometer and magneto and oil pump, respectively.

Connecting rods are alloy steel forgings with hardened liners, pressed into the big ends, the proportions of which are such that the rods may be threaded over the shaft. When in position, the split bronze floating bushes are inserted and the two halves secured to each other by high tensile steel screws which are locked by split pins. The pistons are of aluminum alloy, fitted with three rings, the lower one of which serves as a scraper and returns surplus oil from the cylinder walls through drain holes in the piston skirt. The hollow gudgeon pins float, both in the piston bosses and in the connecting rod small ends and are located endways by bronze buttons pressed into their open ends.

The cylinders have steel barrels, but the inlet and exhaust passages are formed in the aluminum alloy heads which also carry the screwed-in alloy steel valve seats, valve guides, valves and springs. A deep spigot for the head is provided on the barrel with a flange to which the head is bolted by a copper ring spigotted and very carefully fitted in annular grooves cut in the head and barrel flanges. As the rates of expansion of aluminum and steel are different, great difficulty is usually encountered in

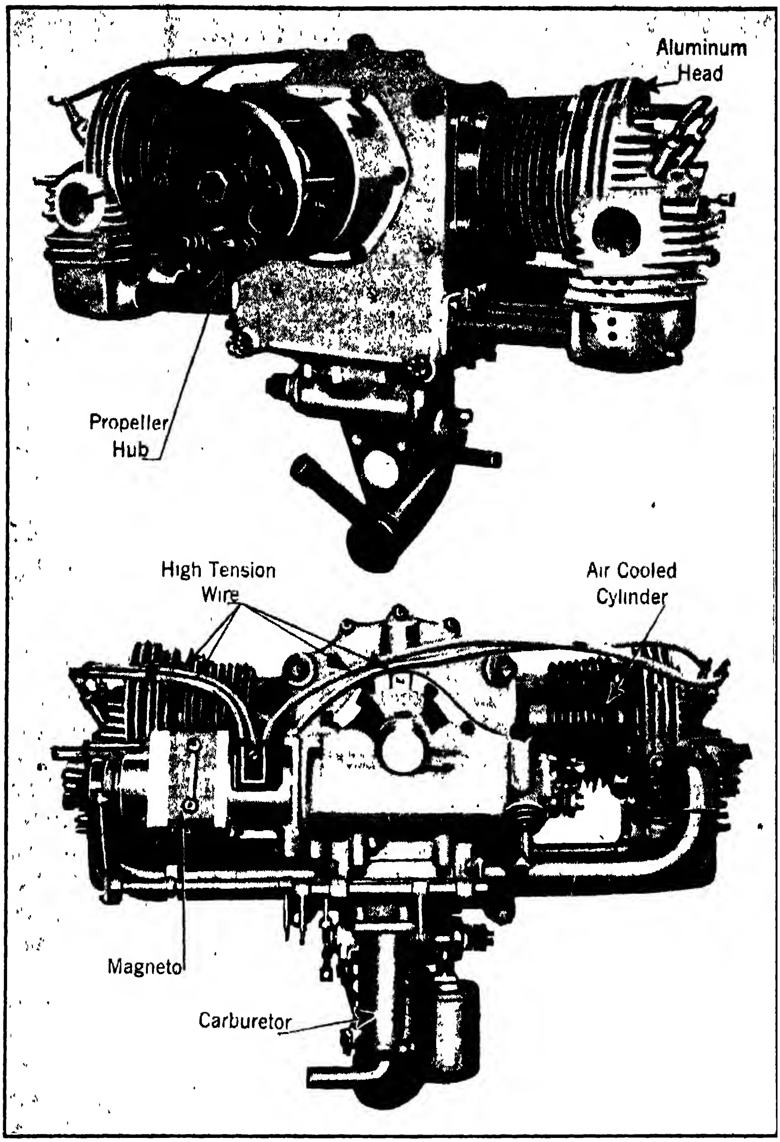


Fig. 131.—Views Showing Bristol "Cherub" Aviation Engine, an Efficient European Design for Low Power Sport Planes.

the maintenance of a really gas-tight joint with this type of head. In the Cherub heads, this difficulty has been entirely overcome by inserting packing pieces of a special alloy, having an unusually low rate of expansion, between the cylinder heads and the heads of the securing bolts. This arrangement, combined with the copper ring joint, has proved so satisfactory that the ends of the bolts are riveted over their nuts, the head and barrel being regarded as one unit which need never be disturbed. The cylinders are secured to the crankcase by a spigotted and flanged joint, a packing ring, serving to make the joint oil tight.

Inlet and exhaust valves are of cobalt-chrome steel and are interchangeable, and three concentric springs are used on each valve. The valve operating gear is somewhat unusual and has distinctive features of considerable importance. The camshaft, which, with its four cams is machined from the solid, runs across the crankcase below the crankshaft and is driven by plain spur gears of ample dimensions. The cams are of the constant acceleration type. The valves are operated by rocker shafts which run parallel to the cylinder.

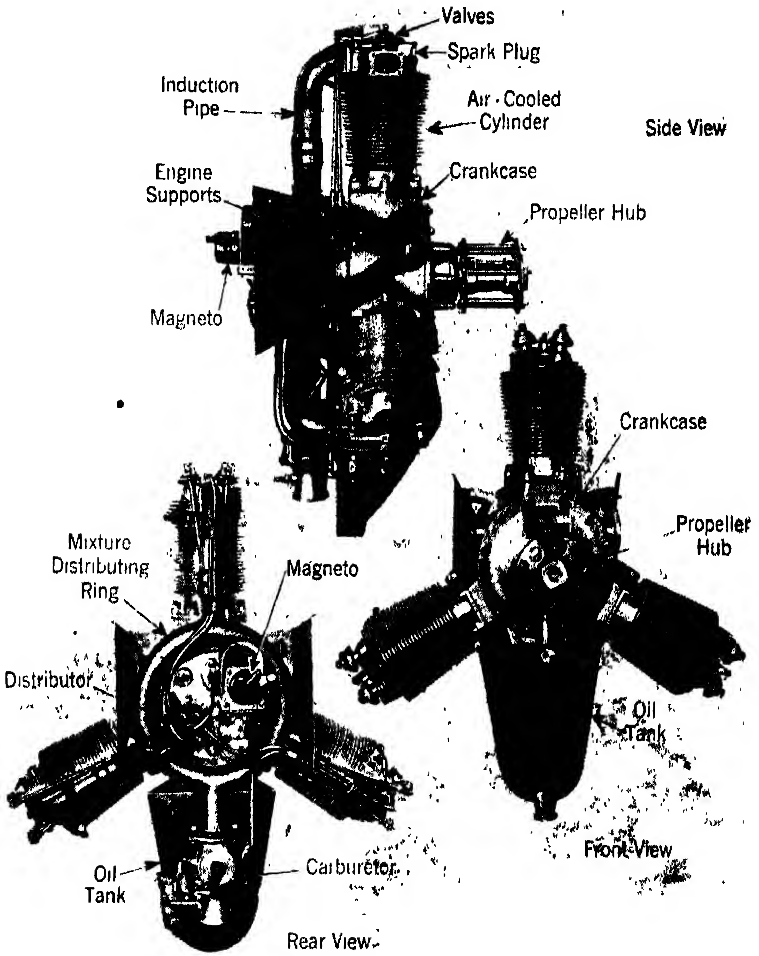


Fig. 132.—Lawrance L 2 Three Cylinder Radial Air-Cooled Engine, Designed Nearly a Decade Ago has Made Many Notable Flights in Small Planes. A—Side View. B—Rear View. C—Front View.

The carburetor is a special type of Zenith with hand operated altitude control of the extra diffuser air type and is bolted to a cast aluminum induction "T" piece which is attached by studs and nuts to a broad facing on the underside of the magneto and pump housing on the rear cover. The throttle and magneto advance and retard are inter-connected by a suitable arrangement of levers and links. The altitude control is independent

except that it is closed automatically if the throttle is closed. The air intake to the carburetor is an exhaust jacketted steel elbow. The induction pipes run from the "T" piece parallel to the cylinders and are fitted into it with airtight expansion joints, and are provided with bosses to take primer jets. The engine is mounted from screwed extensions on the ends of the four crankcase bolts at each corner of the crankcase. A standard connection for a tachometer is arranged on the port side, above the magneto. This engine is shown at Fig. 131. The cylinder bore is 3.5 inches, the stroke 3.8 inches. It has a piston displacement of 75 cubic inches. The

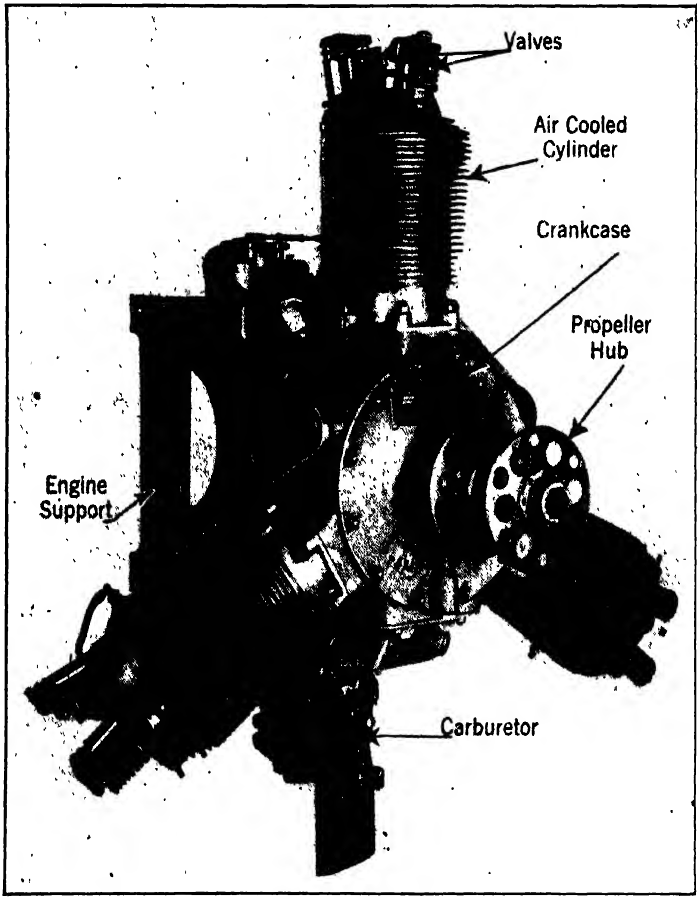


Fig. 132D.—Three-Quarter Front View of Wright "Gale" L 4 60 Horsepower, Three Cylinder Engine.

compression ratio is 5.5 to 1. The dry weight is given at 100 pounds, or 3.1 pounds per horsepower. The length is 9 inches, the width 25.5 inches and the height 20 inches. The center to center of engine bearers is 7.4 inches.

The Wright "Gale" L4 Engine.—This is an improvement on the three-cylinder air-cooled Lawrance engine developed about nine or ten years ago.

The general characteristics do not differ materially from the large Wright engines having nine cylinders though the later types used a different cylinder construction. Of course, the engine is simpler in construction. The cylinder design is similar to that employed on J1 Wright engines but entirely different from that of the J4 and J5 types as can be seen by referring to Fig. 132 D. It develops 60 horsepower at 1,800 r.p.m. It is a logical development and improvement over the Lawrance L2 engine shown at Figs. 132 A, G and C. The bore of that engine was 4.25 inches, the stroke 5.25 inches, and the weight was 140 pounds with carburetor, hub, ignition system and one battery but without oil tank or mounting plates. The cylinders were cast aluminum with steel liners. The carburetor was carried low enough so gravity fuel feed could be used. Lubrication was by full pressure feed type geared pump. This engine is no longer in production, because its selling price due to small output was higher than that of sur-

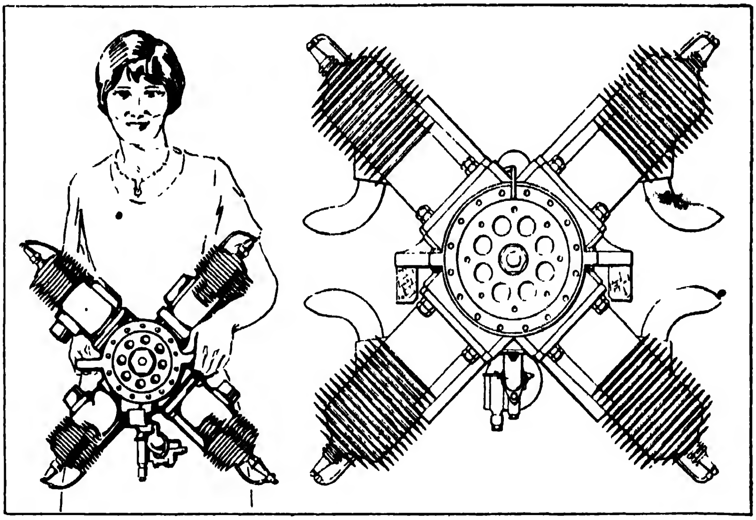


Fig. 133.—Meteormotor Radial Air-Cooled Engine, a Four Cylinder Lightweight. View at Left Shows Small Size of the Engine.

plus stock wartime engines of even greater power, but a considerable number were made and used on light airplanes, seaplanes and for small "Blimp" type non-rigid airships.

The Meteormotor Radial Engine.—This light four-cylinder X-type motor was developed primarily for use in the Meteorplane, a light, sport type that had flown with various motorcycle engines. When powered with the motor illustrated at Fig. 133, the maximum speed of the plane was increased to 90 miles per hour and the ceiling to 15,000 feet. The latest model has copper cooling fins instead of integrally cast iron flanges. The engine operates on the two-cycle principle.

The cylinders are made of the finest grain gray iron, machined both inside and outside, and ground. By a special process, the copper cooling fins are electrically united to the cylinders. The crankshaft is of special heat treated chrome-vanadium steel, machined and ground from a solid 90

pound piece and, when finished, weighs only 6½ pounds. The crankcase is of silicon-aluminum and, for ease in installing, it is fitted with four mounting brackets. Special tubular connecting rods are used in the engine, with steel backed babbitt bearings. The pistons are of fine grain cast iron and carry three rings and weigh but 10 ounces. The valves are of large size and made of tungsten-steel with bronze stems. Both the main and thrust bearings have 13/16 inch diameter balls. An aluminum Zenith carburetor is used, and a special high tension Bosch magneto furnishes the ignition. Lubrication is by pressure and can be regulated from the dash in

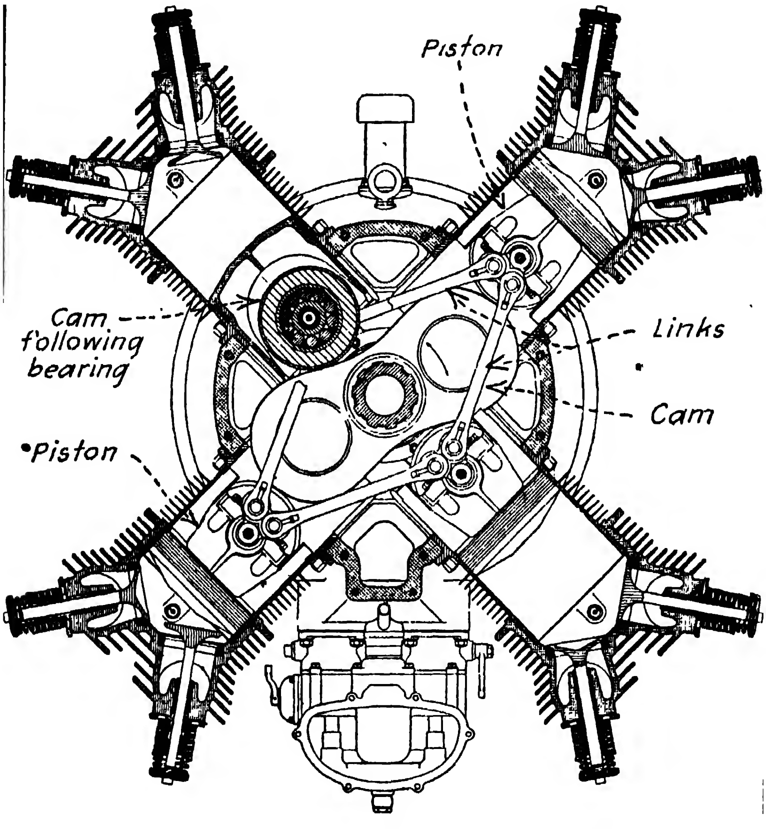


Fig. 134.—Plan Section Drawing of Caminez Engine that Uses Cam Instead of Crankshaft for Operating Pistons.

the pilot's cockpit of a plane fitted with this engine. The complete weight of the Meteormotor, including carburetor, magneto and propeller hub, is only 60 pounds. The cylinder capacity is 72 cubic inches. The engine, which is very smooth in running, develops 20 horsepower, at 2,000 r.p.m., and consumes 1½ gallons of gasoline per hour and ½ pint of lubricating oil. The simplicity of the engine is evident from the layout drawing. It will be seen that, contrary to usual practice with radial engines, the engine bearers are not arranged to attach onto a circular casting, but hold the engine down by means of two flanges attached direct to two longerons. This makes for simple installation.

The Fairchild-Caminez Engine.—This engine is unconventional in the method of converting reciprocating motion of the pistons to rotary motion of the drive shaft. The engine has been thoroughly ground and air tested and other designs of greater horsepower are also in progress. The cylinders are 5⅝ inch bore and 4½ inch stroke and the engine weighs 360 pounds complete with all accessories except starter. Its rating is 150 horsepower. The following description is taken from data published in Aviation.

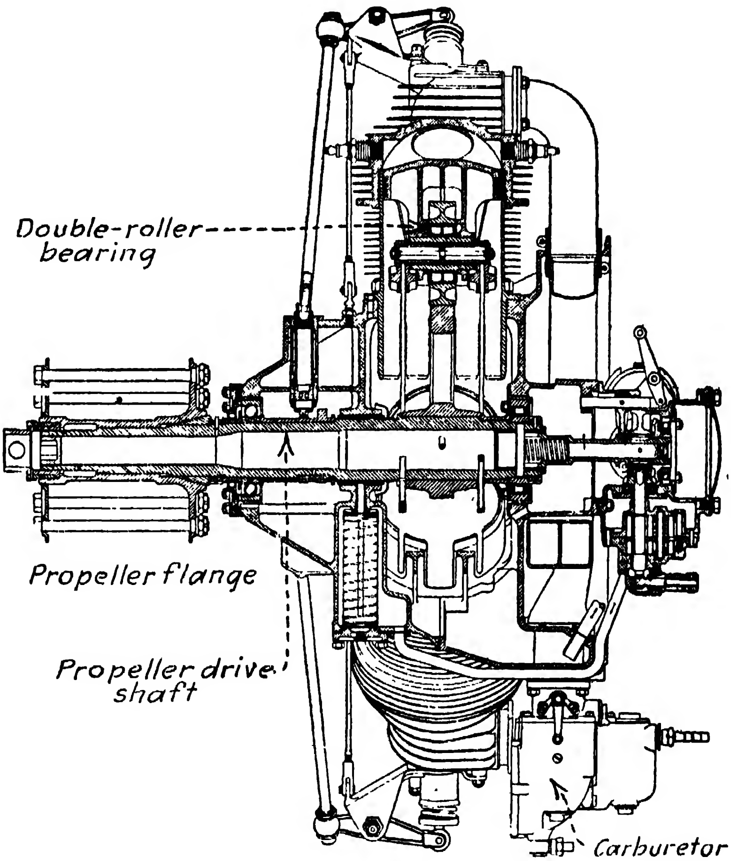


Fig. 135.—Side Section Elevation Drawing of the Caminez Engine Showing Simplicity of Valve Gear and Piston Arrangement.

The Model 447-B engine is a four-cylinder radial engine of the reciprocating piston type operating on the four-stroke cycle. The engine employs the Fairchild-Caminez drive cam mechanism in which reciprocating motion of the pistons is converted into rotary motion of the propeller shaft by means of rollers in the piston operating on a double lobed cam. The mechanism is such that each piston completes four strokes per revolution of the propeller shaft. With the four stroke cycle that is used, each piston, therefore, completes a power stroke every revolution of the shaft. It is

due to this that a high power output is obtained per cubic inch of piston displacement at a low propeller speed, the shaft speed in this engine being one-half that of a crank engine of equal piston displacement for the same power output. Another important difference of this cam engine from the usual crank engine is that the motion of the pistons in opposite cylinders of the cam engine is identical with respect to the engine axis, so that the piston inertia forces balance each other. Perfect running balance is, thereby, obtained without the use of counterweights, the cam engine being the only radial or four-cylinder engine in perfect inertia balance.

In the Fairchild-Caminez engine, the four cylinders are arranged radially about a central rotatable cam as shown in Figs. 134 and 135. This cam is of the double lobed type, shaped generally like a figure 8. A roller bearing is mounted in each piston, the outer race of which acts directly upon this drive cam. Adjacent pistons are connected by a system of links, the contour of the drive cam being so designed that these links maintain the piston rollers in continual contact with the cam.

The main shaft of the engine is a straight alloy steel shaft to which the drive cam is splined. This shaft is supported in the engine case at the rear end by a roller bearing. The front main shaft bearing is a deep groove radial ball bearing which takes all the thrust load on the shaft and part of the axial load. The center plain bearing on this shaft is fitted with large clearance so that it takes but little of the axial load and acts mainly as a means of transmitting the lubricating oil from the case to the shaft, from where it is distributed throughout the engine.

The main engine casing consists of two aluminum alloy castings which are bolted together at the plane through the cylinder axis, eight long studs being employed to hold the casing together. The front, or propeller end casting holds the valve cam followers. The engine auxiliaries, which consist of two magnetos, pressure and scavenging oil pumps, and tachometer drive, are contained in a separate casting that bolts to the rear main engine casing. The engine is mounted in the airplane by means of the rear flange on the engine casing, provisions being made for eight 3/8 inch diameter bolts. The diameter of this mounting flange is 20 inches and the accessories behind this flange are so arranged that no connection on the engine need be disturbed when installing or removing the engine from the airplane.

Four openings are provided in the engine casing which receive the various cylinders. These cylinders consist of hardened steel finned barrels which are screwed and shrunk in special aluminum alloy heads. Bronze inserts are shrunk in the heads for valve seats. Phosphor bronze valve guides are used. The tulip shaped exhaust valve is 2¼ inches diameter, and the mushroom inlet valve is 2½ inches diameter; both valve lifts being 9/16 inches. Pressed steel valve rocker brackets are bolted to the cylinder head at their rear end and attached to the engine case at the front end by a long rod, the construction being such that a firm support for these brackets is obtained without putting too much of the push rod load on the cylinder head casting. The valve rockers are alloy steel drop forgings and have hardened steel rollers which contact on the valve stems. The push rod ball ends are contained in grease tight adjustable screws in the rocker levers, the screws providing means for obtaining proper valve tappet clearances.

Provisions are made to lubricate the push rod ball ends through Alemite connections in the rocker pivot bearings. Since each piston makes four strokes per revolution in the engine, single lobed intake and exhaust cams are mounted directly on the main engine shaft which operates all the valves in the engine. The valve tappet plungers are contained in removable aluminum alloy guides which fit in the nose end of the main engine casing. Rollers are mounted on floating hardened steel pins in the end of the tappet plungers which contact with the valve cams. Small holes drilled through the main engine shaft throw jets of oil on these tappet plunger rollers for lubrication.

The pistons are made of heat treated aluminum alloy and are provided with four narrow compression rings. The pistons are of the slipper type with large bearing areas on their thrust sides. Deep ribs are provided to strengthen the pistons and improve piston cooling. Special double row roller bearings are mounted in each piston, the piston being made with detachable caps to facilitate assembly. A piston pin passes through the hub of these roller bearings at the ends of which link holders are fastened. The links inter-connecting the pistons, consist of alloy steel straps. They have hardened steel pins keyed at their ends which work in bronze bushings in the piston link holders. Ample bearing area is provided for these pins to reduce the unit bearing loads in the bushings. Lubrication of these bearings is obtained by oil jets in the main engine shaft which register with these bearings at every bottom stroke of the piston. The loads on these links and link pin bushings are due to the inertia force of the piston assembly away from the cam. The cam is so shaped that there is a practically constant load on these links at any given engine speed.

The four-cylinder X arrangement lends itself admirably to air cooling. Moreover, the cam mechanism allows a more compact arrangement of cylinders, so that the overall diameter is considerably less than that of the conventional radial of equal power output. This small overall diameter, together with the wide gap between adjacent cylinders results in a small projected frontal area and allows good visibility. The excellent streamline shape of the main engine case and the absence of engine accessories projecting into the streamline, also reduces the head resistance. The installation of this engine requires no engine cowling and tests have shown that the engine will cool satisfactorily at full throttle in a 30 mile air blast.

Detroit Aircraft Engine.—This five-cylinder radial air-cooled engine is from designs by Glen D. Angle and is produced by a syndicate known as the Detroit Aircraft Engine works in which Captain E. V. Rickenbacker, the leading American Ace was actively interested. This engine has been designed exclusively for commercial purposes and with a view to economical quantity production when the demand warrants a large output. This engine, shown at Fig. 136 is easily installed in any type of airplane. It develops 60 horsepower at 1,850 r.p.m. and 75 horsepower at 2,400. It weighs 220 pounds, equipped with two magnetos and ready to fly. The cylinder bore is 4 inches, the piston stroke is 3½ inches, the total piston displacement being 220 cubic inches.

Cylinders are cast individually from the finest grade of nickel-iron Cooling fins are of the circumferential type being integral. Single inlet

and exhaust valves are placed directly in the spherical shaped combustion head; their axes are inclined to the axis of the cylinder so as to obtain the best possible conditions for cooling.

Two spark plugs are provided for each cylinder. Valves are operated through push rods by rockers which are supported on the valve port flanges. The flanges with rocker arms attached, may each be removed as a unit. Valve tappet clearances may be adjusted at the outer ends of the duralumin push rods.

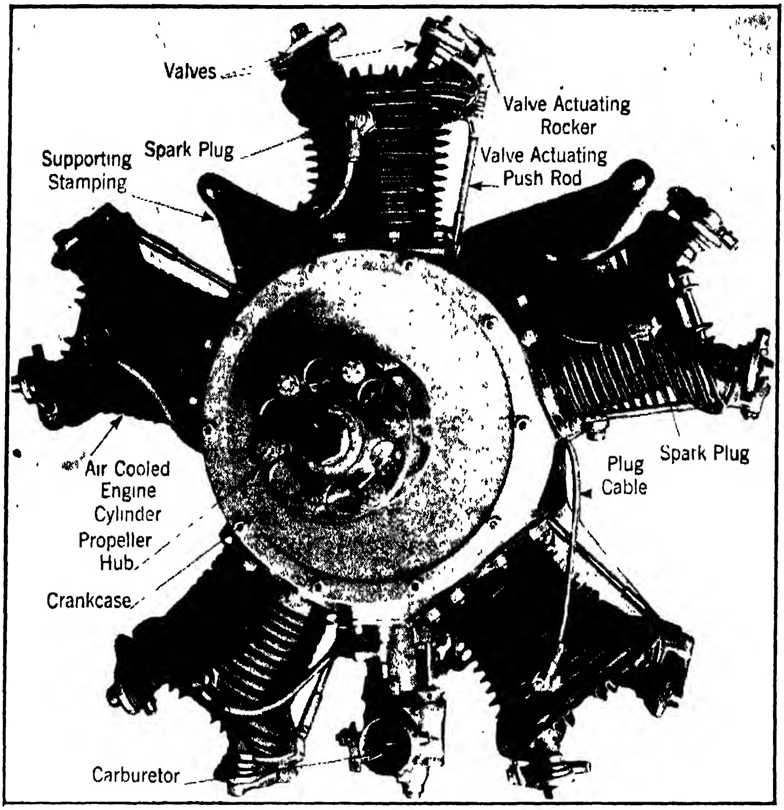


Fig. 136.—Front View of Detroit Five Cylinder Radial Air-Cooled Aviation Engine.

Crankcase is a simple barrel-shaped aluminum casting which contains a cored passage which constitutes the intake manifold. Directly back of each cylinder, there is attached to the crankcase a flange with a pipe leading to the inlet valve of that particular cylinder. Crankcase has one transverse wall containing a boss for supporting the rear crankshaft bearing. To the rear of this wall are the radially disposed bosses receiving the guides for the cam followers, as well as bosses for the engine support studs, and a studded flange for supporting the gear case. Forward from the transverse wall are flanges and openings for attaching the cylinders, besides the carburetor flange and oil drain connection located on the bottom. The simplicity of the installation is clearly shown in Fig. 137, a four arm bracket being bolted to the front fuselage bulkhead.

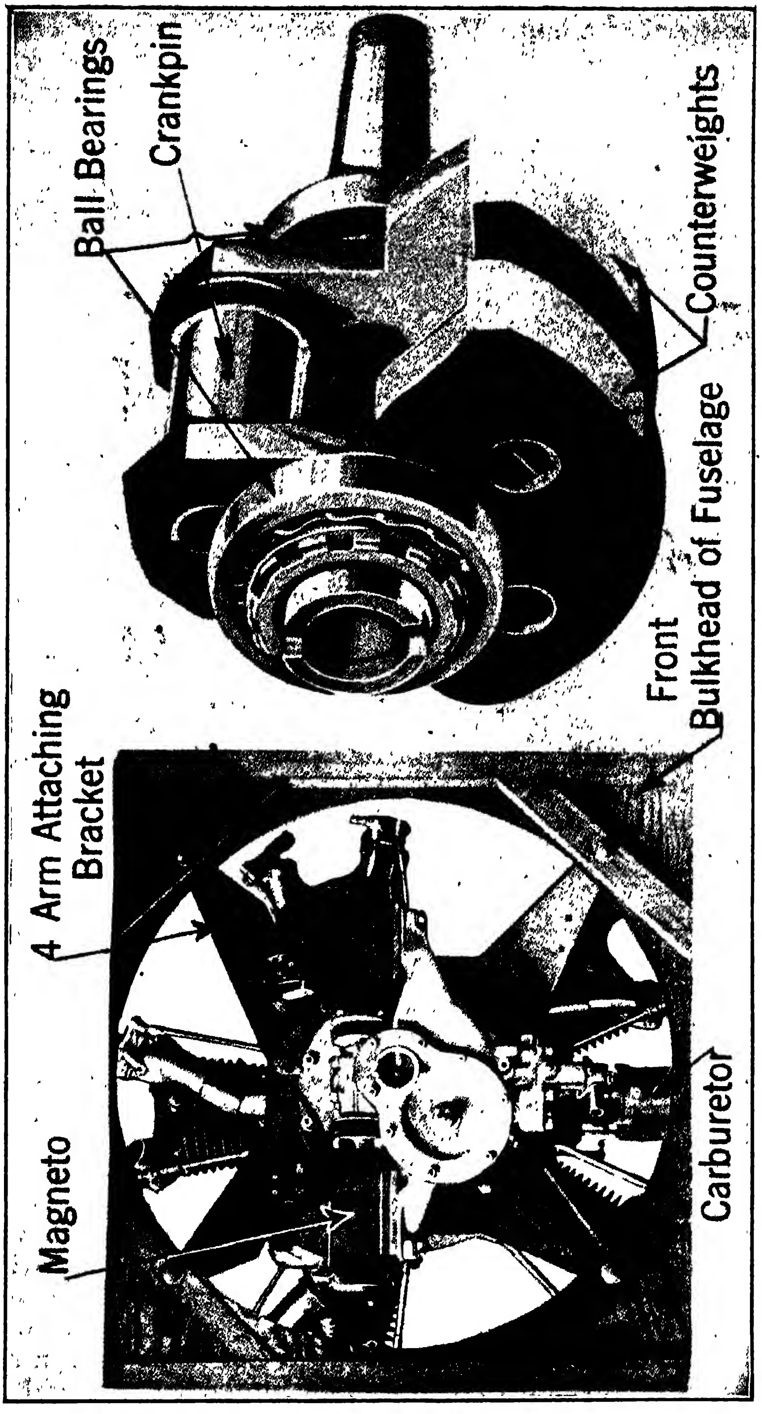


Fig. 137.—View at Left Shows Simple Installation of Detroit Aircraft Engine. The Counterweighted Crankshaft with Anti-friction Bearings is Shown at Right.

The crankcase which is shown at Fig. 138 B has a large opening in front which is sufficient in size to permit the crankshaft and connecting rods being inserted as a unit. Hence the connecting rods and crankshaft counterweights can be fitted before final assembly with the saving of considerable time and with greatest economy. This large opening in front

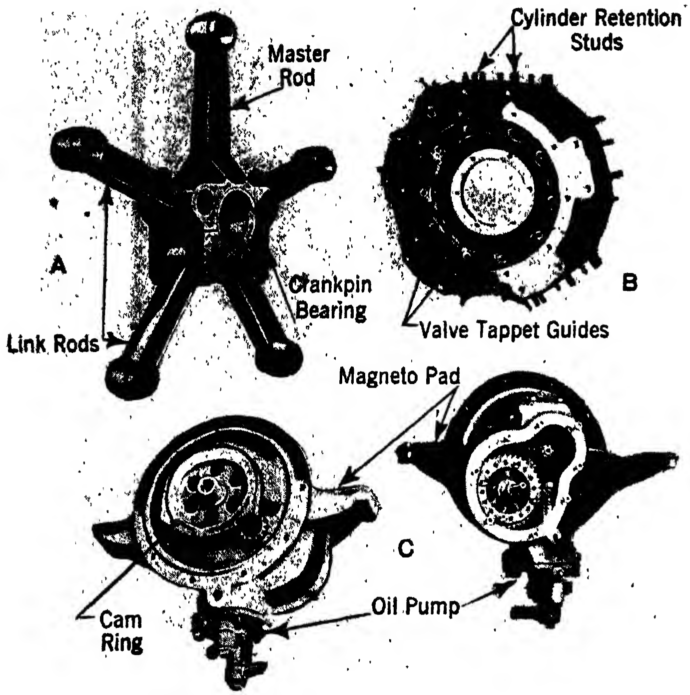


Fig. 138.—Important Parts of Detroit Aircraft Engine. A—Connecting Rod Assembly, Note Substantial Master Rod. B—Front View of Crankcase Showing Valve Tappet Guides. C—Showing Cam Ring and Oil Pump. Drive Group.

is covered by a plate which carries the ball bearing which sustains the propeller thrust. Crankcase is featured by its simplicity and rugged construction.

Crankshaft has a single throw with a counterweight attached at each side. It is supported on two ball bearings; the forward bearing, as stated above, carries the thrust of the propeller. The usual taper and key joint for the propeller hub is provided in front, while at the rear is a driving slot receiving the shaft which drives the cam and other units. The crankshaft shown at Fig. 137 is simple and light, weighing only slightly over ten pounds. It is nevertheless ruggedly designed and made from a suitable drop-forged alloy steel and heat-treated to obtain the best physical properties. The counterweights are securely attached and their use gives almost perfect balance to the rotating and reciprocating parts.

The drop-forged duraluminum connecting rods are of the articulated type—that is, for the top or number one cylinder the rod and cap have full bearing on the crankpin and to these are attached the four linked rods of the other cylinders. The shanks of the rods have the usual H section, and the master rod and cap are held together by four bolts which also locate and secure the pins supporting the inner ends of the linked rods. Bearing on the crankpin is of ample proportions and under full pressure lubrication. Rods are of light weight and loads are comparatively low, and since the babbitt is applied directly to the master rod and cap, the heat dissipating qualities of the bearing are of the best. The connecting rod assembly is shown at Fig. 138 A.

Pistons are made from permanent mold aluminum alloy castings and provided with cooling ribs underneath the head. There are three rings per piston, the lower one serving as an oil scraper, and the piston pins float in both rods and pistons. Pistons are assembled after the crankshaft with connecting rods is positioned in the crankcase—thereupon the cylinders can be attached to the crankcase.

The aluminum gear case shown at Fig. 138 C which is attached to the rear of the crankcase, supports the cam ring and the oil pump, as well as gears for driving same. The gear case may be removed and replaced without affecting the valve timing in the least, therefore when the engine has once been timed there need be no fear of getting it out of adjustment during inspection or while making repairs. One of the unique features of this design is the single ring of three cams which operates all ten valves. Ignition is by two Scintilla magnetos. The carburetor is a special Stromberg. Lubrication is by high pressure pump system, pressures up to 100 pounds per square inch being obtained if desired. Oil passing the relief valve is returned to the inlet side of the pressure pump. Another pair of gears in the pump returns the excess oil to an outside tank. The cylinders extend far into the crankcase and provide an oil sump between the two lower cylinders sufficient to retain and prevent excess oil from draining into these cylinders before being returned to the tank by the scavenging pump. Gears, pistons, and ball bearings on the crankshaft are lubricated by oil sprayed from the bearings and moving parts.

The Super Rhone Engine.—This is a modification of a very popular wartime engine that was built originally to be a revolving cylinder fixed crank type. A special conversion has been designed and patents applied for by Charles E. Quick and the modified engine is produced by a firm who purchased the wartime surplus from the Government. The Le Rhone rotary engine, which forms the basis of this engine, was used by France and England in very large quantities and with excellent results. Converting the engine to a fixed radial type has resulted in a marked decrease in fuel and oil consumption with a resulting increase in power output because the engine can be run faster with fixed cylinders and the horsepower formerly used in turning the cylinders through the air is now delivered to the crankshaft. Most of the American pursuit pilots who were instructed at the Third Aviation Instruction Center of the A. E. F. at Issoudoun, Indre, France received their preliminary training on airplanes equipped

with the Le Rhone engine. The cylinders are of steel with circumferential flanges turned on the barrel and longitudinal flanges milled in the heads. In the rotary form, the gasoline was admitted through a hollow crankshaft, and castor oil was necessary for engine lubrication, and large quantities of oil were thrown out of the exhaust ports as the cylinder assembly revolved. This made this form of engine an exceptionally dirty form to ride behind, which of course, was true of other rotary types such as the Gnome and Clerget. Cowling interfered with the cooling so pilots trained with the rotary engines know the taste and smell of partially burned castor oil very well. None of these faults are found in the Super Rhone.

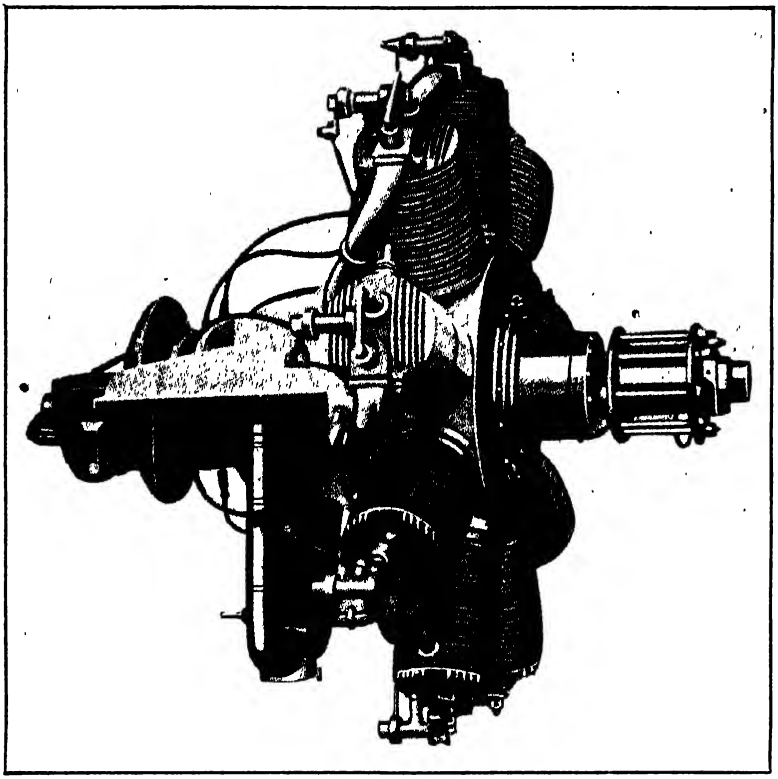


Fig. 139.—The Super Rhone Radial Air-Cooled Engine.

From the nature of its construction, with its taper jointed counterbalanced crankshaft of single throw, complete disassembly can be accomplished by a mechanic of ordinary ability in thirty minutes time, thereby reducing lost flying time in schedule service to a minimum. The saving in weight through the elimination of the radiator and the water piping and connections, as well as the water itself, permits greater pay-load than with the water-cooled engine, and, at the same time, it removes a cause of frequent trouble with consequent forced landings. The absence of the radiator reduces head resistance, giving greater speed and maneuverability, and again reduces cost.

In the Super Rhone engine shown at Fig. 139 any complications in effective air-cooling have been entirely overcome by a simple process which admits fresh air, under atmospheric pressure, to the crankcase, and which forces a complete change of air within the crankcase with each revolution. Thus, excessive accumulation of heat at the center is eliminated by the free passage of fresh cool air, this tending also, by regulation of temperature and pressure, to reduce oil consumption to a minimum.

The engine mounting which forms the basis of the conversion also serves as an intake manifold, is a strong, clean aluminum casting of tested strength. It carries, on its rear and lower side, a flanged face opening to which the carburetor is attached and from which opening the explosive gases are carried to a central chamber from which they are conducted by individual ducts to apertures in the periphery of the casting where the intake pipes that lead to each cylinder are fastened. Thus each cylinder draws its gases as needed from this central chamber, eliminating thereby the excessive amount of gas in any one cylinder which is the most frequent cause of fouling in air-cooled engines and often attributed to lubrication faults. This engine mounting has two properly surfaced flanged extensions toward the rear, two inches wide and thirteen inches long, which form the means of fastening the engine to two engine beds as is the practice in water-cooled types. This cheapens installation costs by the elimination of expensive circular mounting brackets, and readily adapts the engine to installation in the usual manner. The engine mounting, also, carries the magneto and oil pump, and the scavenger pump, and it is to be noted that the engine proper may be withdrawn from this mounting without disturbing fuel, oil or electrical connections and controls.

The crankshaft of the Super Rhone has been carefully and efficiently counterbalanced, and vibration is reduced to a minimum. The rear end of the shaft extends backward about 16 inches, and from it are driven the magneto, oil pumps and distributor. The lubrication of the Super Rhone is effected with ordinary mineral oil of high viscosity, easily obtainable in any locality. Castor oil is not needed. Oil is supplied to the pump from which it is forced through a duct drilled through the length of the crankshaft to the working parts.

SPECIFICATIONS

The general specifications of the Super Rhone engine are as follows:

Type	Air-cooled fixed radial
Number of cylinders	Nine
Bore	105 mm. or 4.13 in.
Stroke	140 mm. or 5.51 in.
Piston displacement	607 cu. in.
Compression ratio	5.2 : 1
Direction of rotation	Counter-clockwise
Fuel-consumption	6½ to 10½ gal. per hr.
Oil consumption	¾ to 1 gal. per hr.
Rated power	120 hp.
Normal speed	1400 r.p.m.
Weight	340 lb.

The installation dimensions of the engine are:

Length, overall	36 in.
Diameter, overall	36 in.
Engine bed flanges, inside clearance	11 9/16 in.
Engine bed bolts, center to center	13 9/16 in.
Distance, bottom of carburetor to engine bed	13 in.
Distance, hub line to carburetor	19 in.

Wright "Whirlwind" J-4A Engine.—Some years ago, through the foresight of Commander B. G. Leighton, then in charge of engine development for the Navy, the Bureau of Aeronautics gave the Lawrance Company an experimental contract for the development of a small nine-cylinder engine,

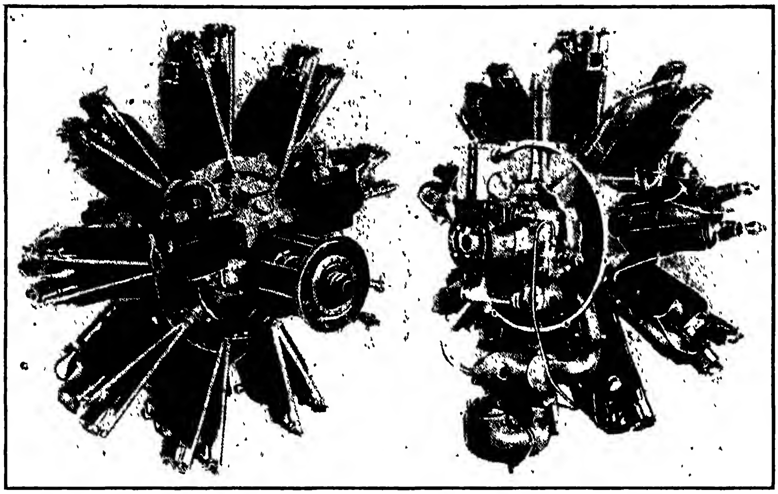


Fig. 140.—Wright "Whirlwind" J 4 Radial Cylinder Engine. At Left—Viewed from the Propeller End. At Right—Rear View Showing Carburetor and Induction System.

using the cylinders developed for the three-cylinder engine. This engine was known as the J-1. A number of these engines were put into Naval service, beginning about four years ago. The J-1 was followed successively by the J-3, J-4 and J-4A, which were developed by the Wright Company after its merger with the Lawrance Company and two recently designed forms the J-4B and the J-5 have also been developed. These engines are now practically standard in the 200 horsepower class, several hundred being now in service. To the Navy, therefore, should go the credit of first putting air-cooled engines to work in this country, though the Army used thousands in its aviation school system in France for training purposes. Owing to its use by the Navy and numerous commercial airplane constructors, the Wright "Whirlwind" series is probably the best known and most widely used of the contemporary radial designs. The J-4A type is shown at Fig. 140 and the improved J-5 is illustrated at Fig. 141. This differs from the earlier type in numerous detail refinements. The valve gear is enclosed and a three-barrel carburetor is used. The problem of fuel distribution is an important one in radial engines.

Various systems of gas distribution have been used. So far, the most sat-

isfactory has been three separate three-cylinder induction-systems, consisting of circular manifolds with cylinder leads 120 degrees apart, each provided with its own carburetor. If a single inlet-valve becomes inoperative, only three of the nine cylinders are affected. This system has the disadvantage of considerable weight and complication. A modification has been used by the Wright Company in which the three manifolds are connected to a single double-barrel carburetor in the J-4A and there is very little more complication in the three-barrel type used on the J-5 engine.

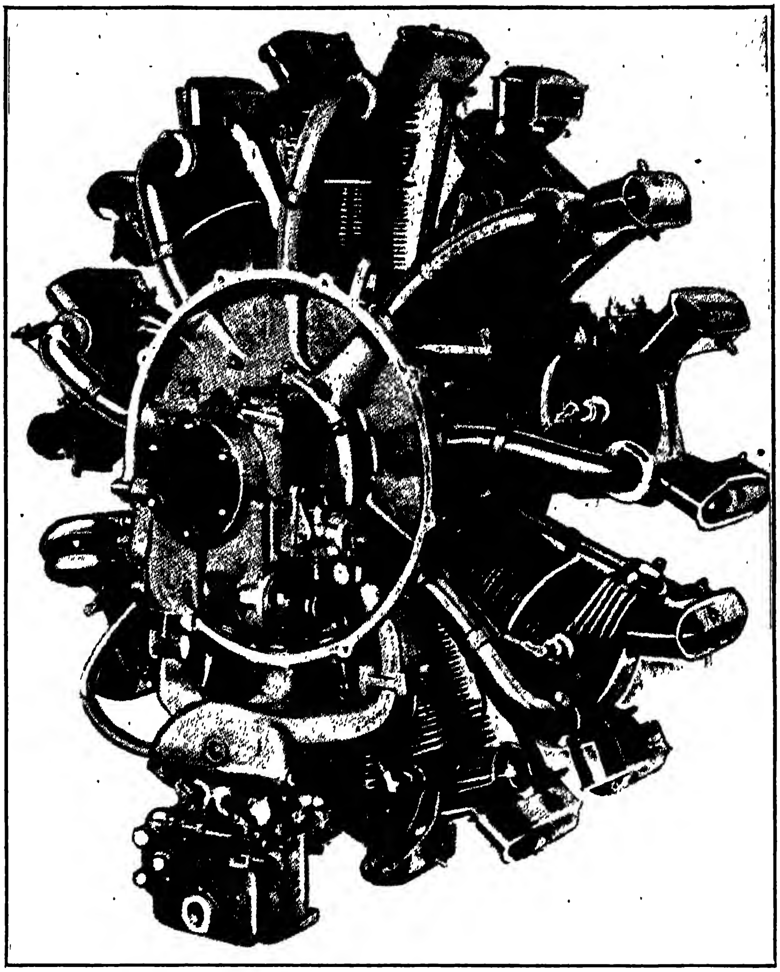


Fig. 141.—Wright "Whirlwind" J 5 with Enclosed Valve Gear Viewed from the Rear.

A third system of considerable promise is the rotary distributing-system, in which a single carburetor is used in conjunction with a small blower from which the gas is taken tangentially to the various cylinders. The blower not only distributes the gas uniformly, but thoroughly mixes the fuel with the air and prevents puddles of fuel from forming in the induction-system. This system is used in the Pratt and Whitney "Wasp" engine.

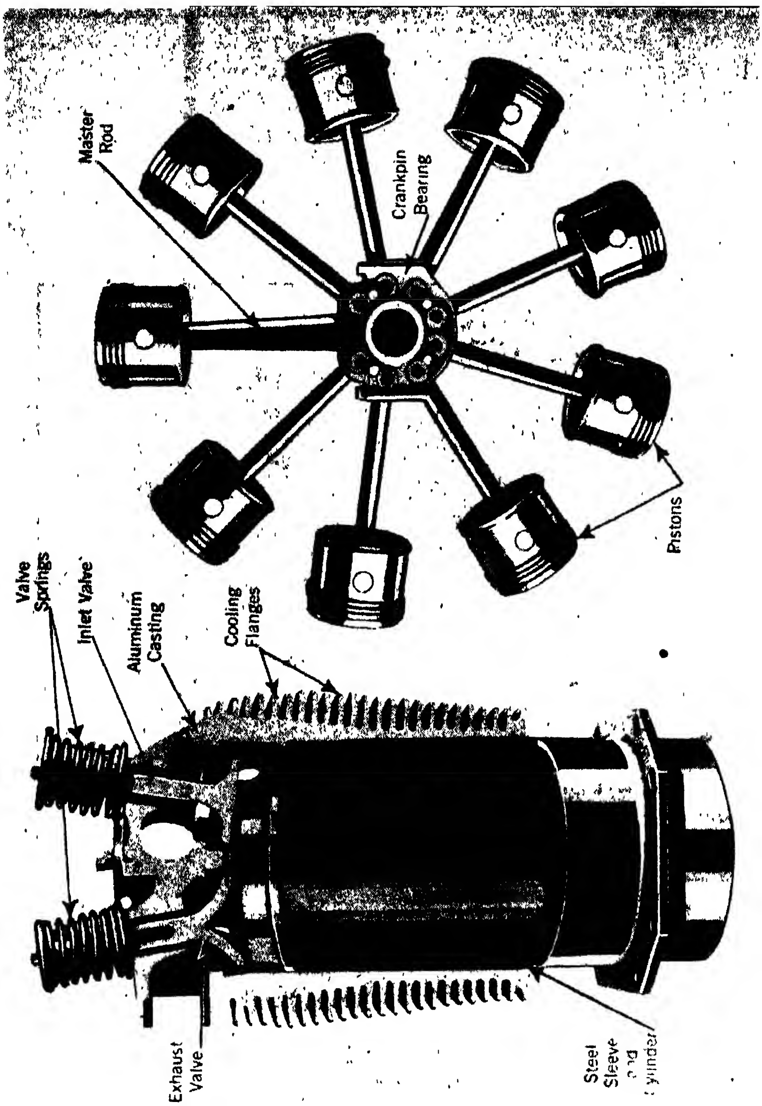


Fig. —Sectional View of Wright "Whirlwind" Engine Cylinder at Left. View at Right Shows Master Rod with the Other Connecting Rods and Pistons Attached to it.

The mechanical balance of a radial engine involves the use of counterweights. These are calculated so as to balance the entire weight of the connecting rods and the pistons attached to the crankpin.

The center of gravity of this system travels approximately in a circle about the crankshaft so that practically perfect mechanical balance can be secured. It has been found that a fair approximation to this method can be secured by balancing one-half the reciprocating and all the rotating weight, considering it all to be on the crankpin. With the longer strokes, the travel of the center of gravity becomes an ellipse, so that it is necessary to determine upon the best circle and to make an approximation of the balance. The concentration of all the connecting rod weights upon one

crankpin results in large counterweights; for example, a 1,650 cubic inch engine may require counterweights that weigh approximately 60 pounds.

The design of the master connecting rod, Fig. 142 involves a study of knuckle-pin travel that is particularly interesting. The knuckle-pin adjacent to the master-rod, which is usually put into the vertical or No. 1 cylinder, travel in nearly circular paths, while the pins for rods Nos. 5 and 6, which are at the bottom, have an ellipselike motion, with the long

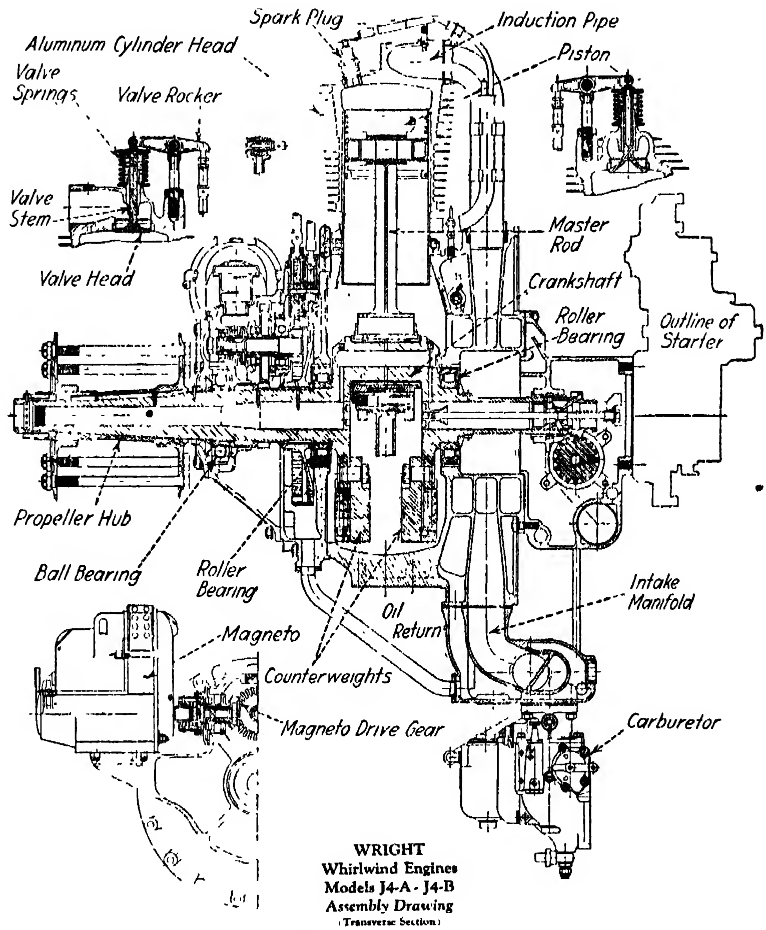


Fig. 143.—Transverse Section Assembly Drawing of Wright "Whirlwind" Engines, Models J 4 A and J 4 B.

axis nearly at right angles to the cylinder center-line and considerably greater than the stroke.

To equalize the compression ratio of the various cylinders, it is necessary either to vary the knuckle-pin centers with respect to the crankpin, or to use different heights of cylinder-pads. As the motion of certain knuckle-pins becomes more and more elliptical the farther removed they are from the crankpin, an effort is made to keep the crankpin small and the

knuckle-pins as close to the center of the pin as possible. The master-rod necessarily receives considerable bending due to the forces applied by the link-rods. For this reason it is necessary to make the master-rod of considerable section in the shank. Due to this condition, trouble might be expected from the added sidethrust on the master-rod piston. No difficulty is experienced from this in practice.

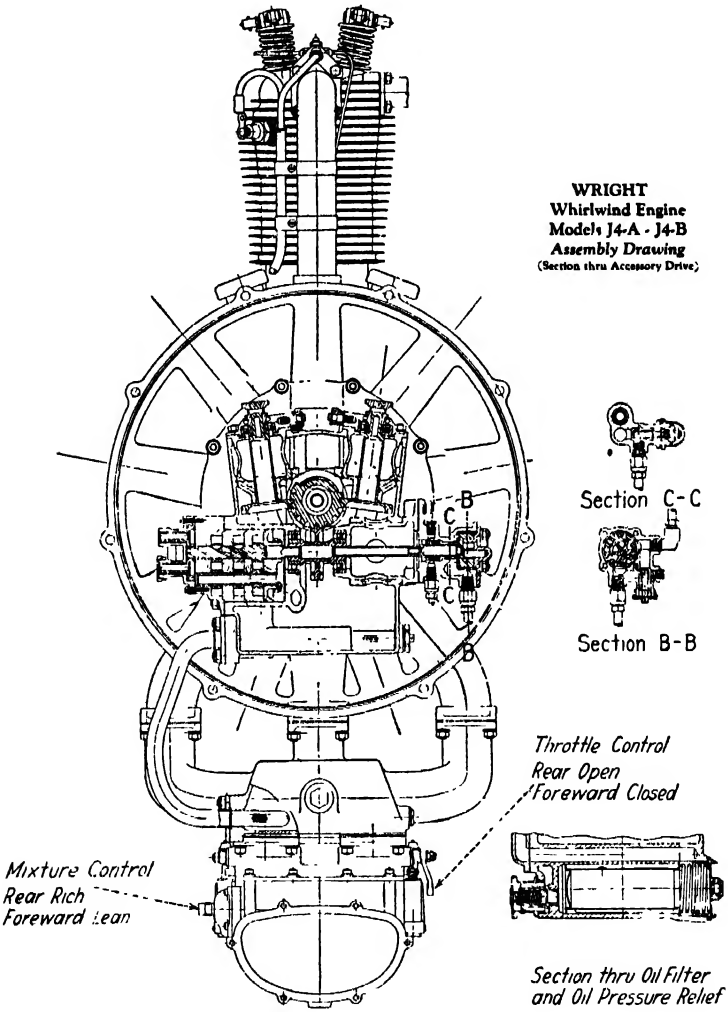


Fig. 144.—Assembly Drawing Showing Section Through Accessory Drive of Wright Models J 4 A and J 4 B Engines.

The general construction of the J-4A and J-4B engines can be understood by study of the transverse section at Fig. 143 and the section taken through the accessory drive casing at Fig. 144. The construction of the J-5 Whirlwind engine can be grasped by inspection of the oiling chart at Fig. 145. The dimensioned installation drawing at Fig. 146 is also valuable in

showing how compact this form of power plant is. The table of specifications which follows is furnished by the Wright Aeronautical Corporation and gives detailed information regarding the three latest forms of Whirlwind engines.

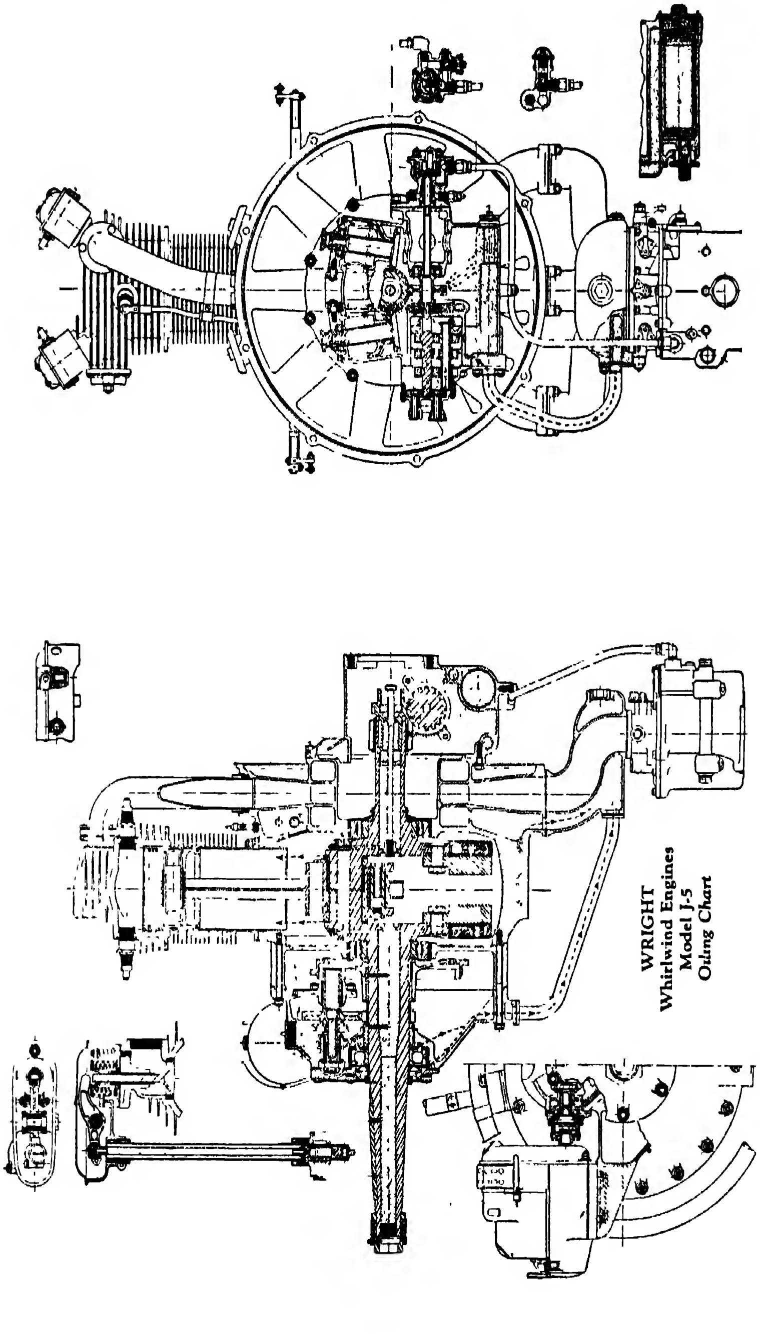
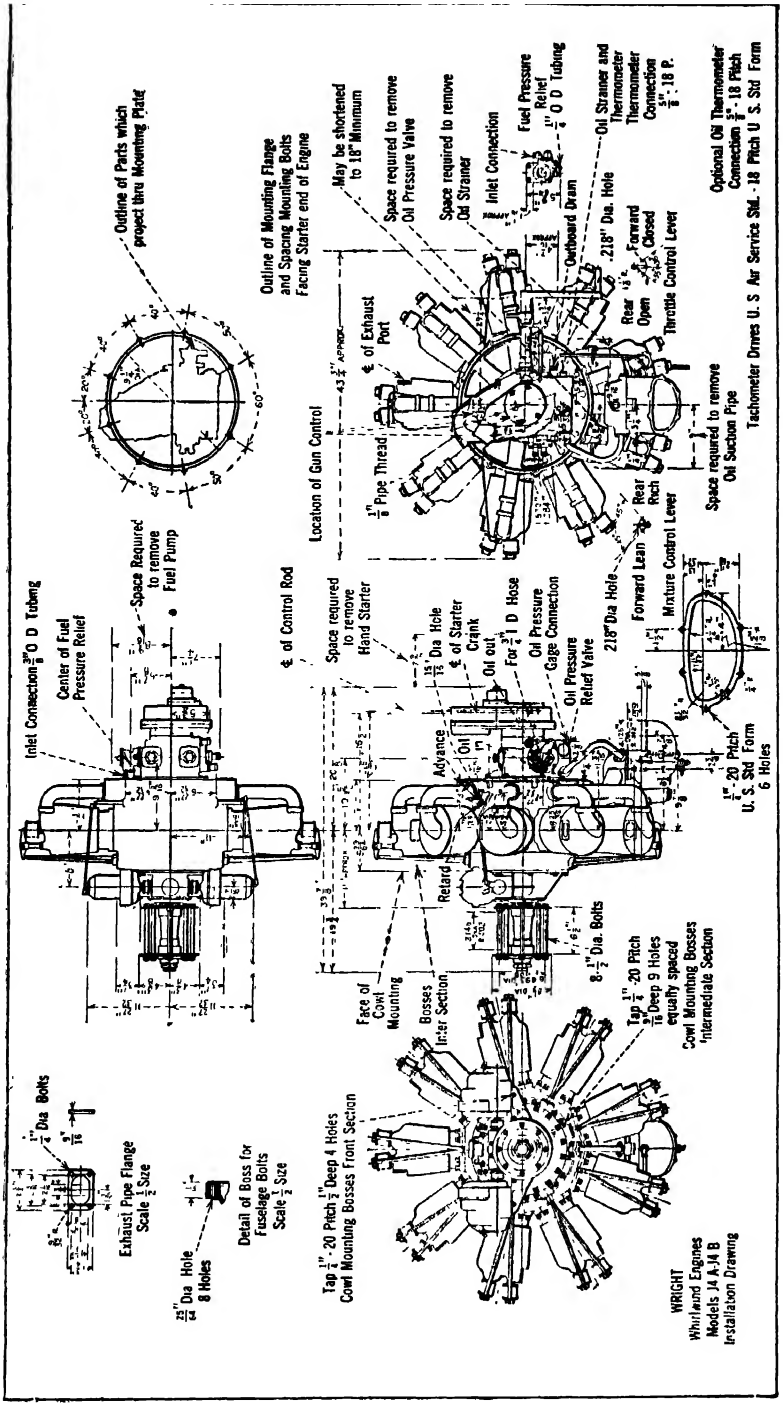


Fig. 145.—Oiling Chart of Wright Model J 5 "Whirlwind" Engines.

TABLE OF SPECIFICATIONS

For J-4A, J-4B and J-5 Engines

General	J-4A and J-4B	J-5
Average H. P. at Normal R. P. M.	212 J-4A 220 J-4B	220
Type	Air-Cooled	Air-Cooled
1. Number of Cylinders	9	9
2. Bore	4.5″	4.5″
3. Stroke	5.5″	5.5″
4. Piston Displacement	788 cu. in.	788 cu. in.
5. Compression Ratio	5.3	5.4
6. Normal Speed in Revolutions per Min.	1800	1800
7. Guaranteed Brake Horsepower, Sea Level at Normal R. P. M. with Aviation Gasoline	200	200
8. Direction of Rotation of Crankshaft (looking at propeller end of engine)	Anti-Clockwise	Anti-Clockwise
9. Direction of Rotation of Cam (looking at propeller end of engine)	Clockwise	Clockwise
10. Tachometer Shaft Speed	½ Crankshaft	½ Crankshaft
11. Direction of Rotation Tachometer Shaft (looking into open end of tach. drive)	Anti-Clockwise	Anti-Clockwise
12. Average weight of engine complete with propeller hub, flange and bolts, carburetor and two magnetos. Without oil radiators, tanks, starting device, gasoline system, propeller, fuel pump or generator	478 lbs.	
13. Average weight of engine complete with carburetor, two running magnetos, spark plugs, high tension wiring and synchronizer drives. Without oil, exhaust pipes, exhaust flanges, starting device, fuel pump, propeller hub, flange and bolts. (Propeller hub Assy. 13 lbs. additional weight)		500 lbs.
14. Diameter Mounting Bolt Circle	19¼″	19¼″
15. Number of Mounting Bolts	8 Total	8 Total
16. Size of Mounting Bolts	⅜″	⅜″
17. Overall Dimensions:	39⅞″	
Overall length of engine Aero-marine Starter		
Eclipse Starter	39⅜″	40 7/32″
Overall diameter outside of rocker arms	43¾″	45″
IGNITION		
18. Magneto Type	Scintilla	Scintilla
19. Direction of Rotation of Magnetos (looking at drive coupling end)	Both Counter Clockwise	Both Counter Clockwise
20. Magneto Speed	1⅛ Times Crankshaft	1⅛ Times Crankshaft
21. Magneto Breaker Point Gap:		
Splitdorf Magneto	.020″-.024″	.012″
Scintilla Magneto	.012″	
22. Spark Plug Point Gap	(A.C.) .020″-.025″	(B.G.) .015″
23. Spark occurs crankshaft degrees before top dead center	30°	30°


Outline of Parts which project thru Mounting Plate
Outline of Mounting Flange and Spacing Mounting Bolts Facing Starter end of Engine
May be shortened to 18" Minimum
Space required to remove Oil Pressure Valve
Space required to remove Oil Strainer
Inlet Connection
Fuel Pressure Relief
1/4" O D Tubing
Oil Strainer and Thermometer
Thermometer Connection
5/8" - 18 P.
Optional Oil Thermometer Connection 5/8" - 18 Pitch
Tachometer Drives U. S Air Service Std. - 18 Pitch U. S. Std Form
Outboard Drain
.218" Dia. Hole
Forward Closed
Rear Open
Throttle Control Lever
℄ of Exhaust Port
43 3/4" APPROX
Location of Gun Control
1/8" Pipe Thread
Space required to remove Oil Suction Pipe
Rear Rich
Forward Lean
Mixture Control Lever
218" Dia Hole
1/4" - 20 Pitch U. S. Std Form 6 Holes
Inlet Connection 3/8" O D Tubing
Center of Fuel Pressure Relief
Space Required to remove Fuel Pump
℄ of Control Rod
Space required to remove Hand Starter
15/16" Dia Hole
℄ of Starter Crank
Oil out
For 3/4" I D Hose
Oil Pressure Gage Connection
Oil Pressure Relief Valve
Advance
Oil In
Retard
Face of Cowl Mounting
Bosses Inter Section
8 - 1/2" Dia. Bolts
Tap 1/4" - 20 Pitch 9/16" Deep 9 Holes equally spaced Cowl Mounting Bosses Intermediate Section
Tap 1/4" - 20 Pitch 1/2" Deep 4 Holes Cowl Mounting Bosses Front Section
1/4" Dia Bolts
Exhaust Pipe Flange Scale 1/2 Size
25/64" Dia Hole 8 Holes
Detail of Boss for Fuselage Bolts Scale 1/2 Size
WRIGHT Whirlwind Engines Models J4 A-J4 B Installation Drawing

GENERAL	J-4A and J-4B	J-5
VALVES AND TIMING (With hot or running tappet clearance)		
24. Intake Closes	60° A.B.C.	60° A.B.C.
Intake Opens	8° B.T.C.	8° B.T.C.
25. Exhaust Opens	60° B.B.C.	60° B.B.C.
Exhaust Closes	8° A.T.C.	8° A.T.C.
26. Exhaust Remains Open (Crankshaft Degrees)	248°	248°
27. Intake Remains Open (Crankshaft Degrees)	248°	248°
28. Valve Lift	7/16"	
29. Valve Tappet Clearance (both valves)		
Hot or running clearance	.060"	.060"
Cold clearance	.010"	.040"
FUEL SYSTEM		
30. Carburetor Type	Stromberg NA-U5G	Stromberg NA-T4
31. Carburetor Settings:		
Venturi (choke)	1¾"	1 7/16"
Metering Jet	‡43	‡51
Accelerating Well Bore (Upper)	7/32"	¼"
(Lower)	‡14	‡14
Main Jet Air Bleed	‡53	‡55
Idle Metering Jet	‡58	‡60
Idle Air Bleed	‡50	‡40
Float Level below parting line	1½"	1 3/16"
32. Guaranteed Fuel-Consumption. Lbs. per H. P. Hour at 200 H. Normal R. M. P.	.60	.53
33. Correct Pressure on Fuel Supply. Lbs. per Sq. In.	4	4
LUBRICATING SYSTEM		
34. Guaranteed Oil Consumption, lbs. per H. P. Hr. Not Over	.025	.035
35. Correct Oil Pressure (lbs. per sq. in.) at Normal R. P. M. at recommended oil temperature	60	60
36. Quantity of oil circulated per minute at normal pressure and temperature (lbs. per min.)	27	27
37. Minimum Safe Quantity of Oil in whole system, gallons	2	2
38. Maximum Permissible Outlet Temperature of oil under worst conditions*	180° F.	180° F.
39. Desired maximum oil outlet temperature in normal operation*	120° F.	120° F.
40. Speed of Oil Pump	Crankshaft Speed	Crankshaft Speed
41. Direction of Rotation of Oil Pump (looking at driven end of shaft)	Anti-Clockwise	Anti-Clockwise
42. Hose Connections Required between engine and lubricating system:		
Inlet and Outlet — Inside Diameter	¾"	¾"
Inlet and Outlet — Number of Pieces	2	2
43. Valve Spring Loading (Plus or minus 10%).		

	Valve Closed Length	Valve Closed Load	Valve Open Length	Valve Open Load
J-5				
Inner	1 19/32″	8.4 lbs.	1 7/32″	13 lbs.
Intermediate	1 19/32″	13.3 lbs.	1 4/32″	22.4 lbs.
Outer	1 19/32″	20.1 lbs.	1 3/32″	33.6 lbs.
J-4B				
Inner	1 3/4″	15.1 lbs.	1 5/16″	24.4 lbs.
Outer	1 3/4″	22.2 lbs.	1 5/16″	37.9 lbs.

[4] Inlet temperature of oil will be approximately 10° F. lower.

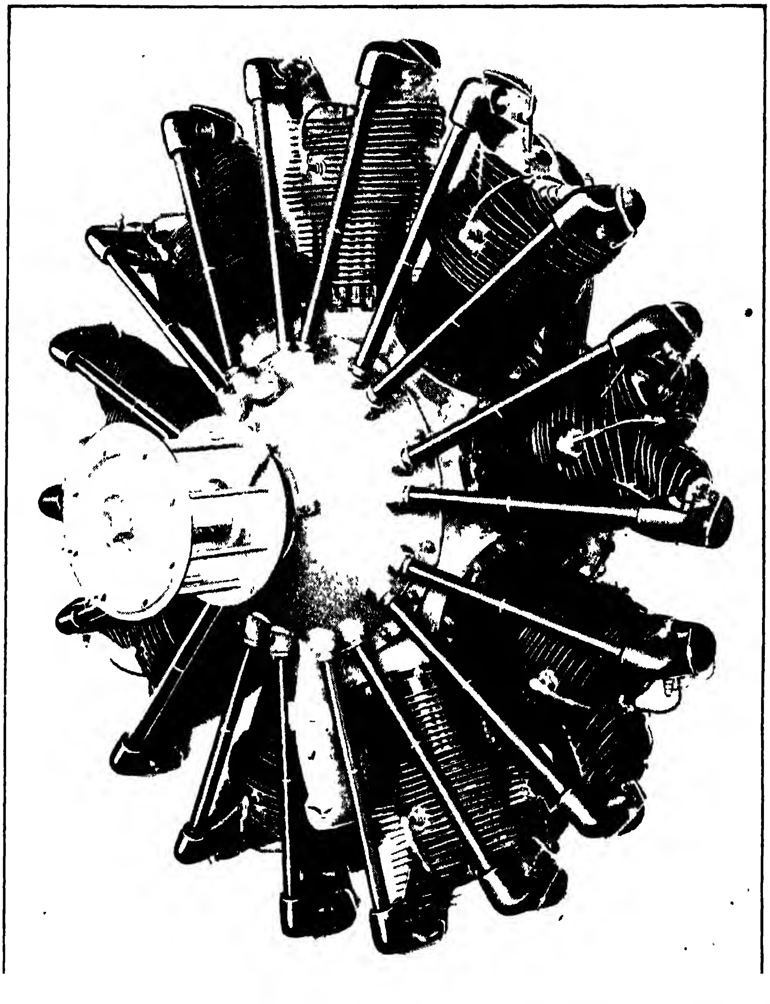


Fig. 147.—Three-Quarter Front View of Pratt and Whitney "Wasp," a Nine Cylinder Radial Air-Cooled Engine.

Pratt and Whitney "Wasp" Engine.—The Pratt and Whitney "Wasp" was primarily designed and developed to meet the exacting requirements of a power plant for use in the high speed single and two-place military fighting planes. The general features of construction are shown in the external views, Figs. 147, 148 and 149. The cylinder disposition of the radial type alone provides uniform and maximum cooling for each cylinder. The cylinder is built up with an aluminum head screwed and shrunk on a steel barrel with integral fins. The valve seats are bronze shrunk into the aluminum head, while the spark plugs screw directly into the aluminum.

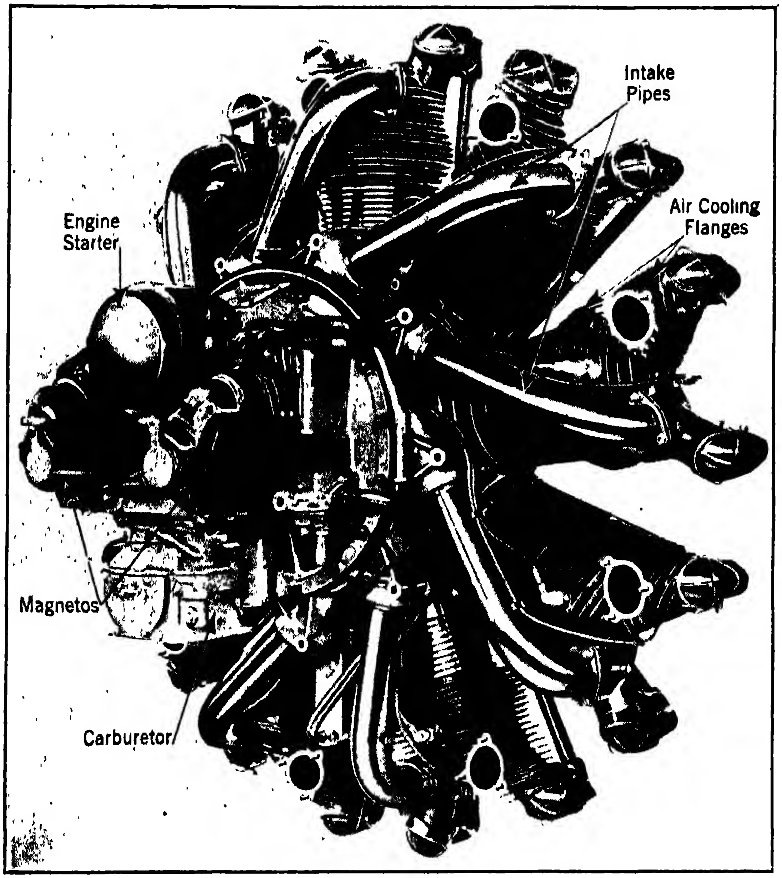


Fig. 148.- -Three-Quarter Rear View of Pratt and Whitney "Wasp," Showing Ignition Magnetos, Carburetor, Eclipse Starter and Induction Pipes.

It has been found possible to operate "Wasp" engines on straight aviation gasoline at rated power with .48 fuel-consumption. This is an excellent measure of good cylinder cooling. On standard straight fuel 130 pounds m.e.p. is obtained with zero pressure in the intake system, while 140 pounds has been consistently developed with 30 per cent benzol or its equivalent.

The rocker boxes are formed as a part of the cylinder head castings,

and are provided with a quickly detachable cover held on by a bale wire, completely enclosing both the rocker arm and the valve spring. In conjunction with the telescopic push rod enclosure tube, the whole valve gear is thus enclosed, but quickly accessible for inspection. The rocker arms are mounted on small ball bearings which obviate the need for daily lubri-

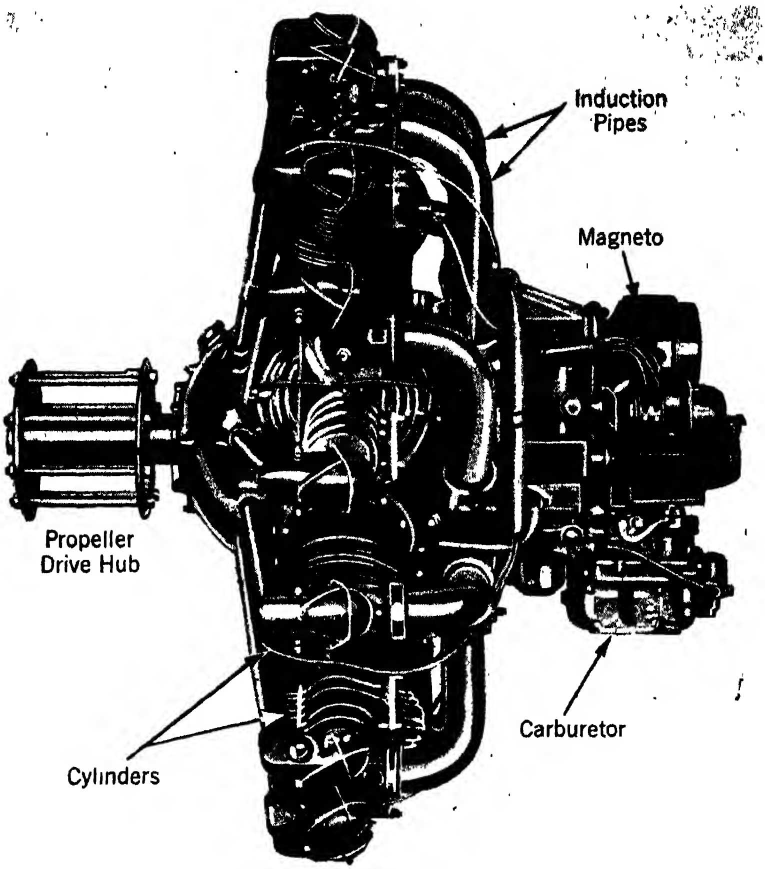


Fig. 149.—Side View of Pratt and Whitney "Wasp" Engine.

cation. Timing compensation for the elongation of the cylinders is provided in the cam and tappet.

Grouping all the accessories in the rear has resulted in an engine very easy to cowl, and provides for unusually symmetrical fuselage lines. Equally as important as these aerodynamic features is the complete protection from the elements of all accessories. Ready access may be provided to all the accessories through inspection doors in the fuselage. In the one group provision is made for the two magnetos, starter, two synchronizer heads, tachometer, generator, oil pump, and fuel pump as well as a step-up gear for the supercharger. The "Wasp" engine is equipped with a Gen-

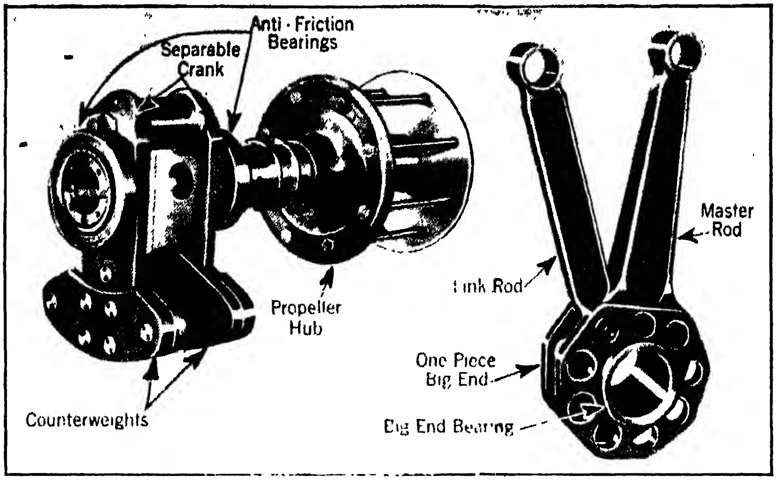


Fig. 150.—Pratt and Whitney "Wasp" Engine Crankshaft and Two of the Connecting Rods. The Big End of the Master Rod is Made in One Piece, the Crankshaft is a Built-Up Assembly to Permit Installation of Master Rod.

eral Electric type of rotary distributor and supercharger. This type lends itself extermely well to radial design, and with little addition to the weight.

The "Wasp" design incorporates a number of fundamentally new and different characteristics. To provide for high crank speeds a solid big end is used for the master rod, together with a built-up crankshaft as shown at Fig. 150. The split master rod has long been one of the limit-

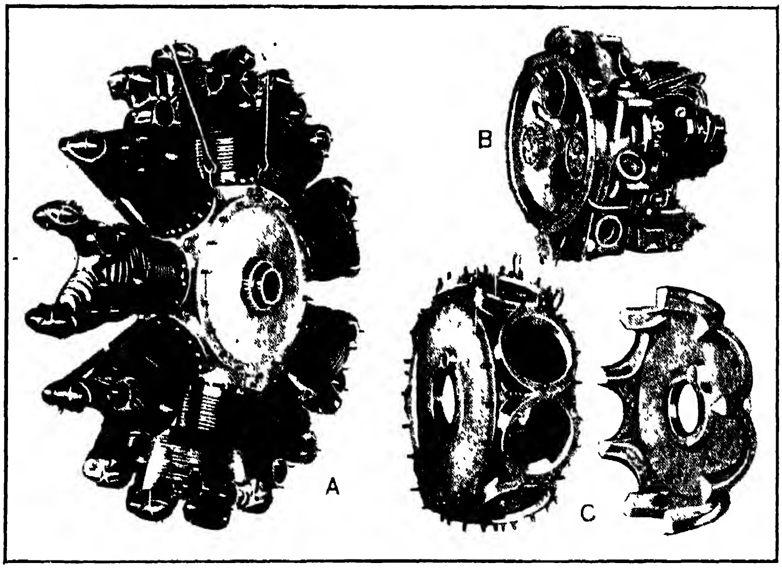


Fig. 151.—"Wasp" Cylinder and Crankcase Assembly at A can be Removed from Superchargers and Accessory Drive Assembly Shown at B. C—How Crankcase is Made of Two Duralumin Forgings and One of the Forgings before Machining.

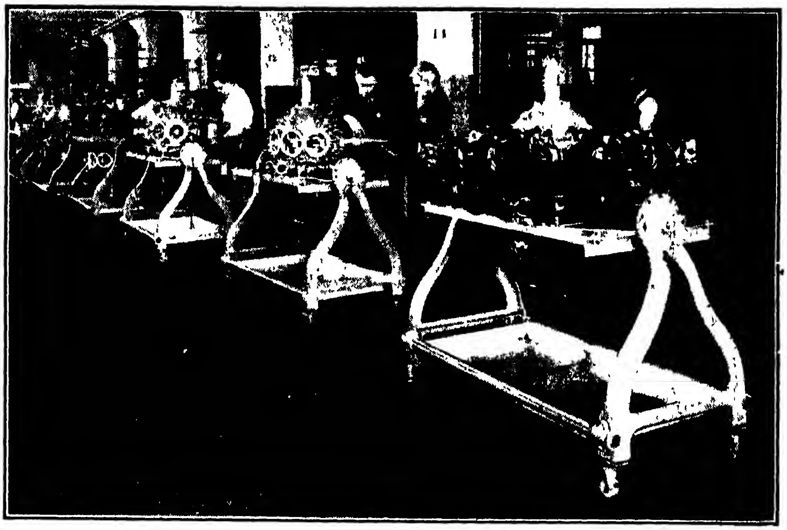


Fig. 152.—Typical Bay of Pratt and Whitney Assembly Floor Showing Progressive Assembly of "Wasp" Aircraft Engines.

ing factors for high crank speeds on the larger radial types. Rigid crankshaft support is absolutely necessary. For this purpose a forged instead of cast aluminum crankcase as shown at Fig. 151 C is used, consisting of two identical pieces facing each other and held together by nine through bolts, one between each two cylinders. This construction is both extremely strong and very light. Moreover, the load is equally divided between the two main bearings, and consequently no working takes place between the crankcase sections. By means of the solid master rod, large diameter crankshaft, unique crankcase, and method of engine support, high crank speeds have been provided for.

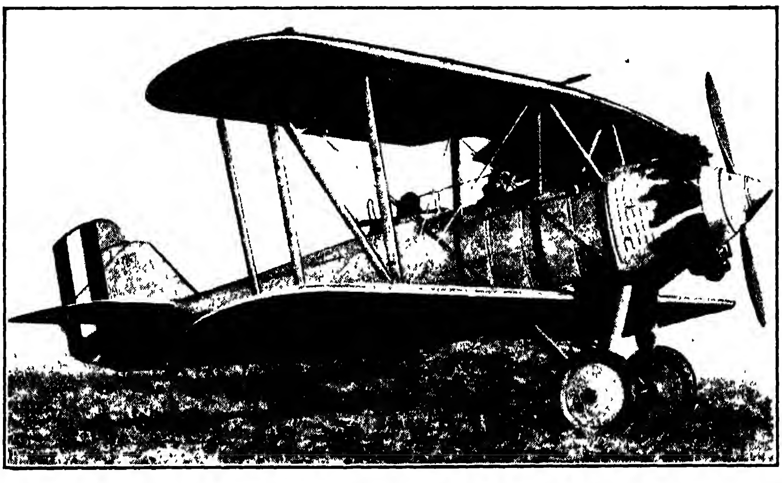


Fig. 153.—Vought "Corsair" Service Biplane Equipped with Pratt and Whitney "Wasp" Engine.

The rear sections, of which there are two, the blower and rear, form an assembly by themselves as shown at Fig. 151 B. This makes it possible to divide the engine into two units for assembly as well as service work, the power end consisting of the main case and nose, the shaft, rod, pistons, cylinder shown at A and valve gear, and the accessory end, including the mounting supercharger and gearing, and all accessories and their drives. Should occasion arise, the "power end" can be removed from an airplane and another substituted without disturbing the "accessory end." This is possible because the engine is supported on the blower section, and the support is arranged as nearly on the center of gravity of the engine, and as far removed from the crankshaft as possible. As will be seen by examination of the photograph showing an assembly floor in the factory, the design is such that assembling can be done with groups that are bench assembled first and then united to form the complete power plant. Attention is directed to the special engine assembly stands shown at Fig. 152.

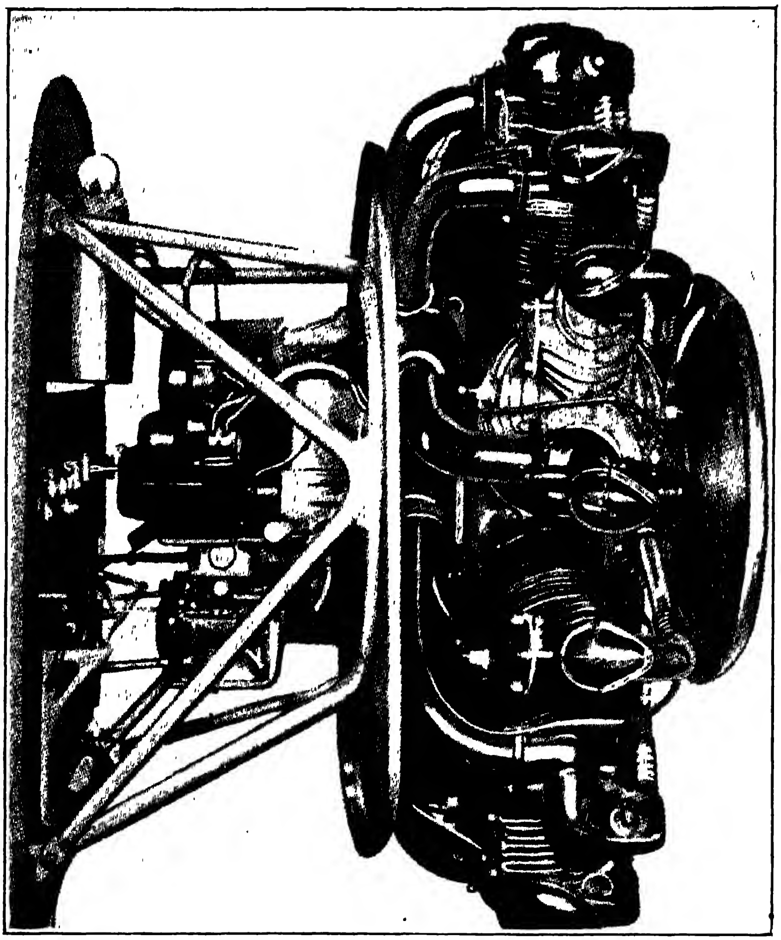
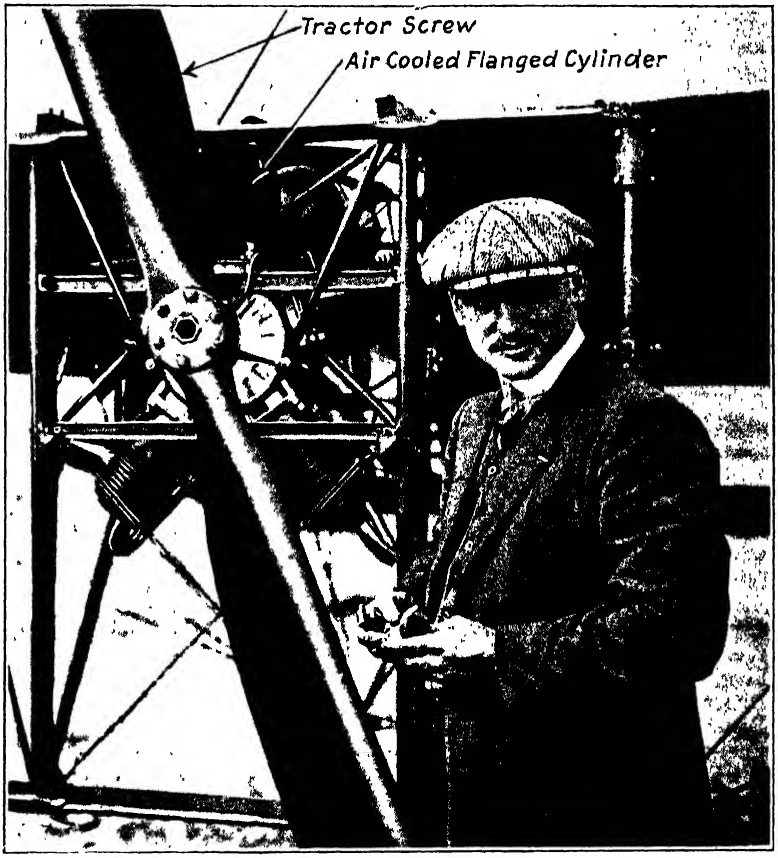


Fig. 154.—Installation of "Wasp" Radial Air-Cooled Engine in Vought "Corsair" Plane is Easily Accomplished by Fuselage. Front End Construction Shown above.

The accessories are carried at the rear of the crankcase and behind the mounting, where they are completely enclosed in the forward bay of the fuselage just ahead of the fire-wall. Ready access to all the accessories is provided through a single opening in the cowling on either side of the airplane, which is normally closed by side plates provided with louvers as shown at Fig. 153 which shows a Vought Corsair biplane, "Wasp" equipped.



Anzani, a Pioneer Air-Cooled Engine Designer, Testing his Five-Cylinder Air-Cooled Aviation Motor Installed in an Early Model Bleriot Monoplane. Note Exposure of Flanged Cylinders to Propeller Slip Stream and High Resistance of Engine and Plane Parts.

The accessory drives were a considerable problem, since it was desired to use the minimum number of gears, preferably all of the spur type, to arrange for removing the engine from the airplane without dismounting anything else and still have as compact and light an assembly as possible. When it is considered that drives must be provided for two magnetos, a starter, two synchronizer-heads, a tachometer, generator, oil pump, and fuel pump, as well as for a step-up gear for the supercharger, a total of 10 drives. it will be realized that the solution was not easy. It was finally

solved by using three lay-shafts approximately 120 degrees apart, all driven from the crankshaft by a single spur-gear. An Eclipse momentum starter engages with the uppermost shaft through a dog-clutch. Provision is made on the shaft for a generator-drive by using a pair of bevel-gears. Each of the lower shafts drives a Scintilla magneto at its outboard extremity. In addition, three bevel-gears provide a vertical drive, both upward and downward, for each lower lay-shaft. Upward, they drive directly the synchronizer-heads and indirectly, by a small worm-gear, the tachometer. Downward, one drives the fuel pump and the other the oil pump. The crankshaft gear previously mentioned is a dual spur, one gear of which drives the supercharger impeller through a spur step-up.

This arrangement is shown at Fig. 151 B. The mounting plate and the manner in which it is attached to the fuselage by triangular braces built up of tubing is clearly outlined at Fig. 154. This construction permits the removal of the entire power plant with its mounting plate and struts by removing four bolts, one each at the apex of the triangular members formed by the juncture of vertical and horizontal struts. Of course, controls, instrument drives and oil and fuel lines must be disconnected. The mounting shown is that of the Vought at Fig. 153 with all cowling removed.

SPECIFICATIONS OF WASP ENGINE

Type	Air-cooled Fixed Radial
No. Cylinders	9
Bore	5.75"
Stroke	5.75"
Displacement	1344 cu. in.
Average H. P. at Sea Level 425 H. P at	1900 R.P.M.
Weight	650 lbs.
Length Over All	43⅜"
Diameter Over All	50⅝"
Distance Mounting Flange to End of Propeller Hub	29⅛"
Fuel-Consumption (Lbs per H P. Hr.)	.52
Oil Consumption (Lbs. per H. P. Hr.)	.025

QUESTIONS FOR REVIEW

1. Name important advantages of air-cooled engines
2. Must all air-cooled engines be of the radial type?
3. Outline important considerations in designing air-cooled cylinders with special reference to cooling fins.
4. What materials are used in air-cooled cylinders?
5. How are exhaust valves cooled in air-cooled engines?
6. Describe simple opposed cylinder engine.
7. How does the Fairchild-Caminez engine differ from conventional practice?
8. Describe connecting rod arrangement of Wright Whirlwind engine.
9. How are cylinder sleeves fastened in aluminum cylinders?
10. When aluminum alloy is used for cylinder heads, how does it resist melting from high explosion temperatures?

CHAPTER IX

AVIATION ENGINE DESIGN AND CONSTRUCTION—WATER-COOLED ENGINES

Wartime Water-Cooled Types—Curtiss OX Series—Hispano-Suiza Model A—German Mercedes Engine—The Liberty Motor—Water-Cooled Cylinder Development—Wet Sleeve Construction—Wright Water-Cooled Engines—Packard Aircraft Engines—Packard Oil-Cooled Valves—Packard Multiple Cluster Valve Springs—Packard Lubricating System—Curtiss Aviation Engines of Recent Design—Beardmore Six Cylinder Engine—Sunbeam 18 Cylinder Engine—Many Materials Used in Aviation Engines.

Wartime Water-Cooled Types.—In order to enable the reader to understand the great progress that has been made in water-cooled aviation engine design as well as in radial air-cooled types, before describing the

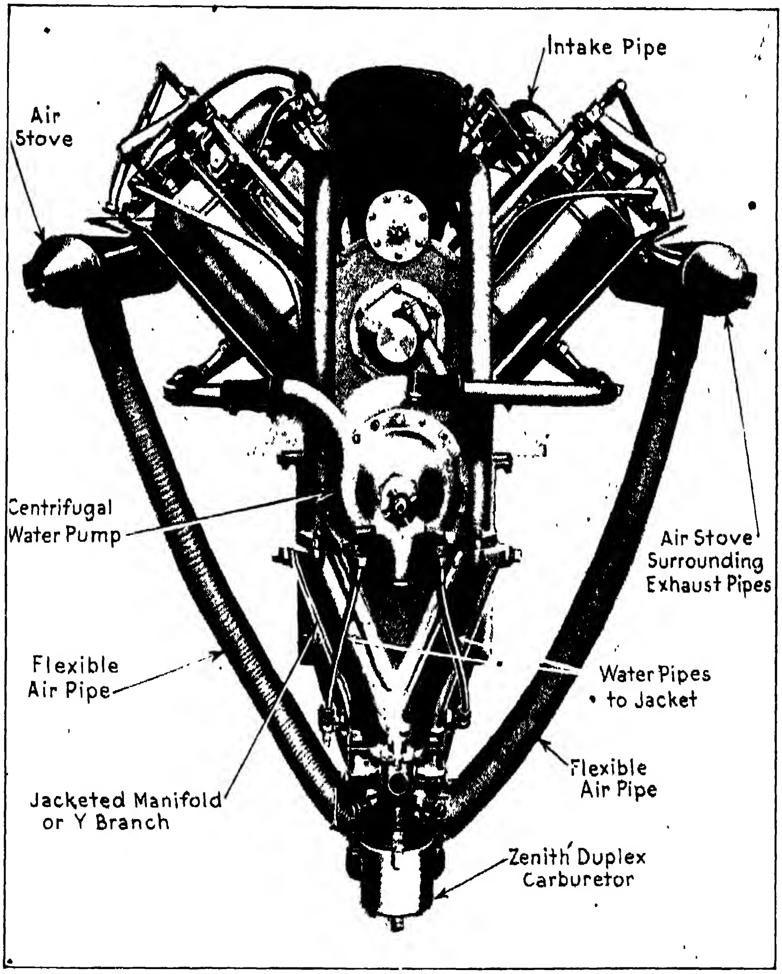


Fig. 155.—Rear View of Curtiss OX 2 90 Horsepower Airplane Motor Showing Carburetor Location and Hot Air Leads.

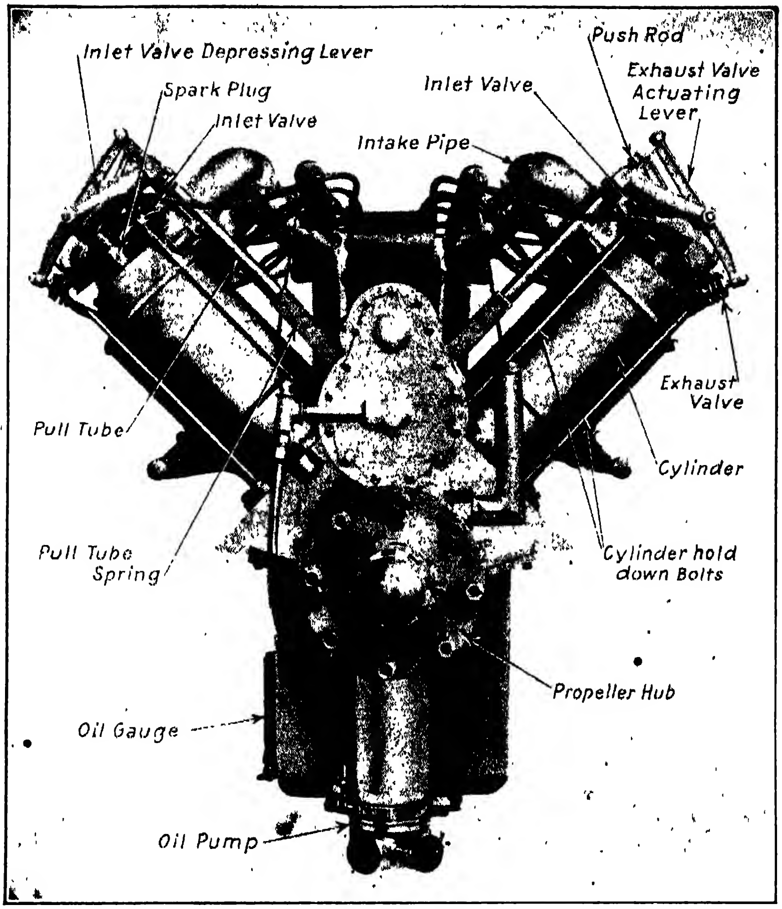


Fig. 156.—Front View of Curtiss OX 3 Airplane Motor, Showing Unconventional Valve Action by Concentric Push Rod and Pull Tube.

more recently designed engines, it will be instructive to show and briefly describe the engines that were most popular nearly a decade ago. These include the Curtiss OX series, the Hispano-Suiza and the Liberty motor. Many of these engines are still in use because the Government had surplus stocks of thousands of these power plants at the close of the war and many of these have been used in civilian airplanes as they were sold at low prices to the public. The most practical of the present day water-cooled engines are refinements of these earlier types.

Curtiss OX Series.—The Curtiss OX series motors had eight cylinders, 4-inch bore, 5-inch stroke, delivered 90 horsepower at 1,400 turns, and the weight turns out at 4.17 pounds per horsepower. This motor shown at Figs. 155 and 156 has cast iron cylinders with monel metal jackets, overhead inclined valves operated by means of two rocker arms, push-and-pull rods from the central camshaft located in the crankcase. The cam and push rod design is extremely ingenious and the whole valve construction was very light for that early day. This motor is an evolution from the

early Curtiss type motor which was used by Glenn Curtiss when he won the Gordon Bennett Cup at Rheims in the early days of aviation. A slightly larger edition of this type motor is the OXX 5, as shown at Fig. 157 which has cylinders 4¼ inches by 5 inches, delivers 100 horsepower at 1,400 turns and has the same fuel and oil consumption as the OX type motor, namely, .60 pound of fuel per brake horsepower hour and .03 pound of lubricating oil per brake horsepower hour.

Hispano-Suiza Model A.—The Model A Hispano-Suiza is of the water-cooled four-cycle Vee type, with eight cylinders, 4.7245-inch bore by 5.1182-inch stroke, piston displacement 718 cubic inches. At sea level it develops 150 horsepower at 1,450 r.p.m. It can be run successfully at much higher speeds, depending on propeller design and gearing, developing proportionately increased power. The weight, including carburetor, two magnetos, propeller hub, starting magneto and crank, but without radiator, water or oil or exhaust pipes, is 445 pounds. Average fuel-consumption is .5 pound per horsepower hour and the oil consumption at 1,450 r.p.m. is three quarts per hour. The external appearance is shown at Fig. 158.

Four cylinders are contained in each block, which is of built-up con-

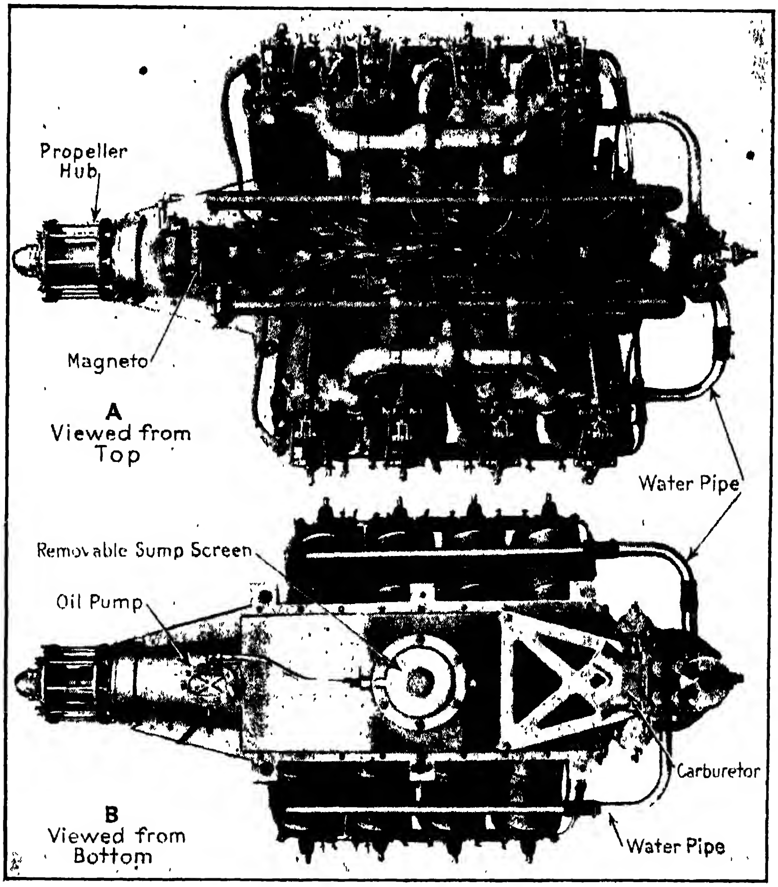


Fig. 157A and B.—Top and Bottom Views of Curtiss OXX5 Engine.

struction; the water jackets and valve ports are cast aluminum and the individual cylinders heat-treated steel forgings threaded into the bored holes of the aluminum castings. Each block after assembly is given a number of protective coats of enamel, both inside and out, baked on. Coats on the inside are applied under pressure. The pistons are aluminum castings, ribbed. Connecting rods are tubular, of the forked type. One rod bears directly on the crankpin; the other rod has a bearing on the outside of the one first mentioned.

The crankshaft is of the five-bearing type, very short, stiff in design, bored for lightness and for the oiling system. The crankshaft extension is tapered for the French standard propeller hub, which is keyed and locked

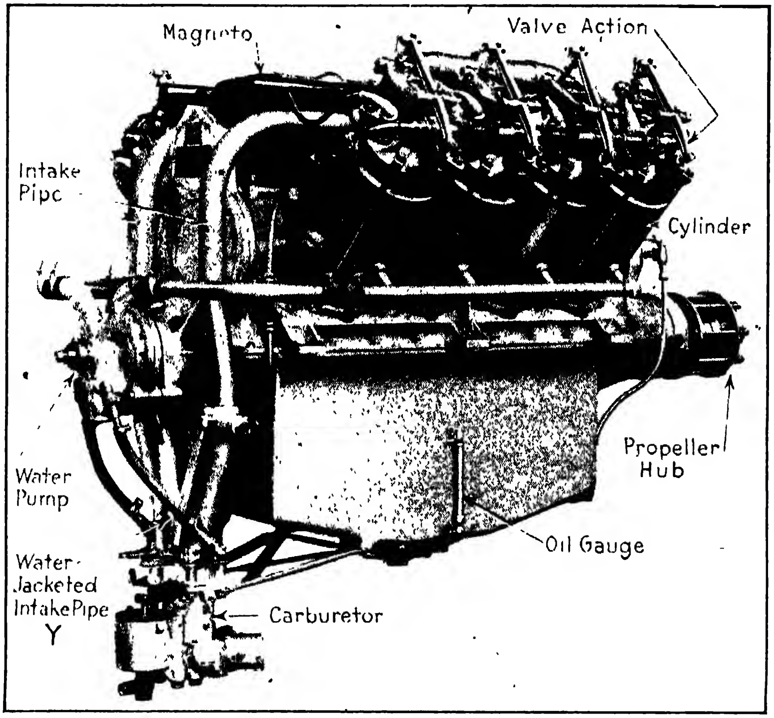


Fig. 157C.—Curtiss OXX5 Aviation Engine is an Eight Cylinder V Type Largely Used on Early Training Machines and Used Today on Moderate Powered Planes for Civilian Use.

to the shaft. This makes possible instant change of propellers. The case is in two halves divided on the center line of the crankshaft, the bearings being fitted between the upper and lower sections. The lower half is deep, providing a large oil reservoir and stiffening the engine. The upper half is simple and provides magneto supports on extension ledges of the two main faces. The valves are of large diameter with hollow stems, working in cast iron bushings. They are directly operated by a single hollow camshaft located over the valves. The camshafts are driven from the crankshaft by vertical shafts and bevel gears. The camshafts, cams and heads of the valve stems are all enclosed in oil tight removable housings of cast aluminum.

Oiling is by a positive pressure system. The oil is taken through a filter and steel tubes cast in the case to main bearings, through crankshaft to crankpins. The fourth main bearing is also provided with an oil lead from the system and through tubes running up the end of each cylinder block, oil is provided for the camshafts, cams and bearings. The surplus oil escapes through the end of the camshaft where the driving gears are mounted, and with the oil that has gathered in the top casing, descends through the drive shaft and gears to the sump.

Ignition is by two eight-cylinder magnetos firing two spark plugs per cylinder. The magnetos are driven from each of the two vertical shafts by small bevel pinions meshing in bevel gears. The carburetor is mounted between the two cylinder blocks and feeds the two blocks through aluminum manifolds which are partly water jacketed. The engine was sometimes equipped with a geared hand crank-starting device.

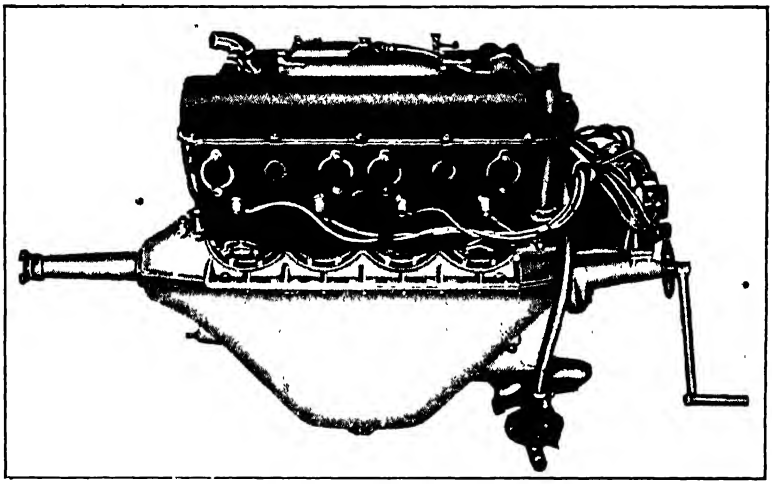


Fig. 158.—The Simplex Model A Hispano-Suiza Aviation Engine, a Very Successful Early Form.

So fine was the design of the Hispano-Suiza, so advanced the engineering ideas embodied in it, so splendid the workmanship, and so stringent the control of material, that even today, eight years after its production was discontinued, hundreds of Hispano-Suiza engines are giving splendid service.

The Hispano-Suiza aeronautical engine was originally designed at Barcelona, Spain, in September, 1914. Within less than a year, although the design was radical and without precedent, several experimental engines had been run successfully under the supervision of the technical department of the French Air Service. Its manufacture was taken up in this country by the predecessor of the present Wright Aeronautical Corporation and large production was underway on the Model A and a larger 300 horsepower type when the Armistice was declared.

At the conclusion of the war, the Wright Hispano-Suiza was still the world's finest aircraft engine, but both our Army and our Navy realized

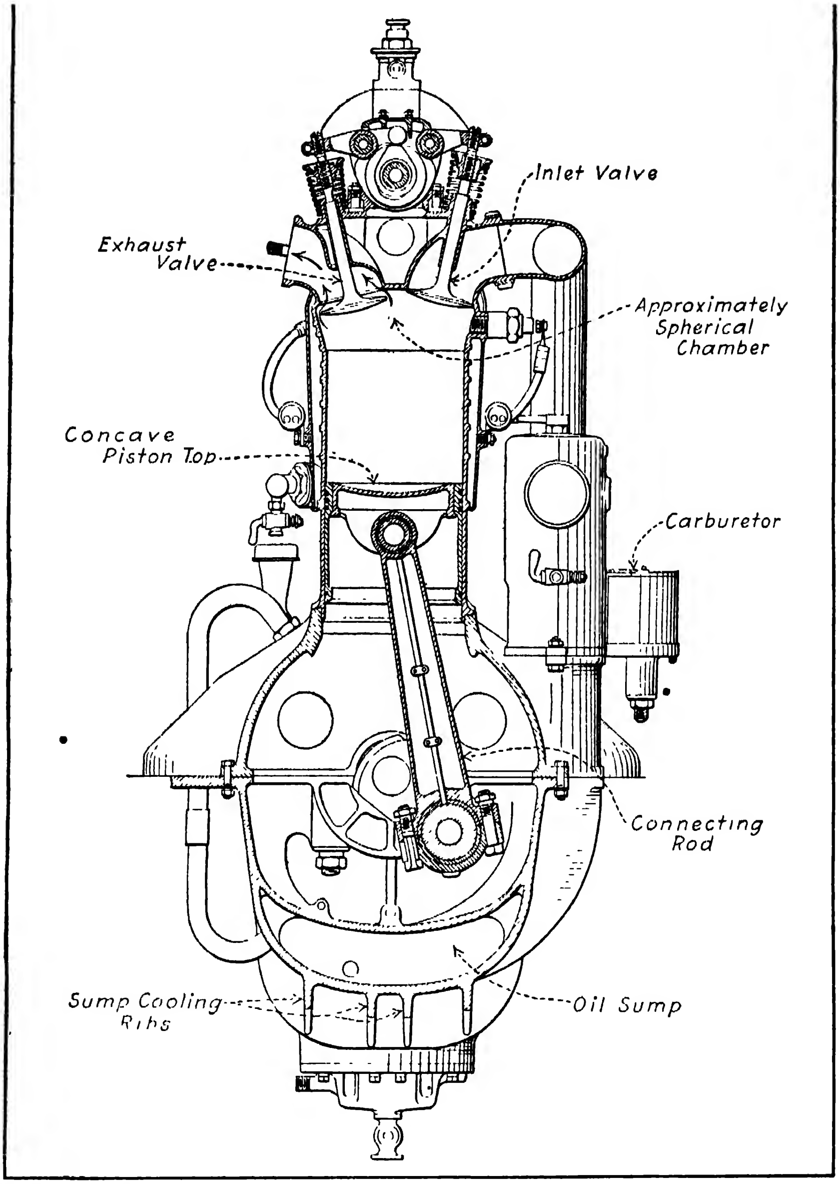


Fig. 159.—Mercedes Aviation Engine Cylinder Section Showing Approximately Spherical Combustion Chamber and Concave Piston Top, a Pre-War Type that was the Ancestor of Many Modern Designs.

that new and improved engines must be constantly developed if our standing was to be maintained. With tremendous reductions in personnel and expenditures, they had no possible use for thousands of the engines which had been produced under the stress of wartime demand. Commercial aviation was in its infancy and could not be expected to absorb any such quantity of engines for years to come. The Government had but one course to follow: to sell the engines for whatever it could get, to firms or persons will-

ing to purchase and store them, to take all the risks of depreciation and obsolescence, and to gamble on being able to sell them in small quantities to commercial aviators at something of a profit. These surplus engines have been disposed of in rather large lots from time to time all over the country. They have been bought at astoundingly low prices by various individuals and firms, some of whom were directly connected with the aircraft industry and some of whom were not. Conversions have been designed so these engines could be used in speed boats as well as aircraft.

German Mercedes Engine.—The sectional view of the cylinder of the German Mercedes engine at Fig. 159 is interesting because it depicts a form that was undoubtedly the ancestor of numerous more modern forms. The section is that of a cylinder of a six-cylinder vertical type and it incorporated many features that were worked out in racing automobile practice. The early Hall-Scott engines were based to a large extent on this design, as was the Liberty motor. The more modern Packard aircraft engines are a logical refinement and improvement on this early form. The Renault twelve-cylinder V engine of the water-cooled form was another early form based on the original Mercedes design shown.

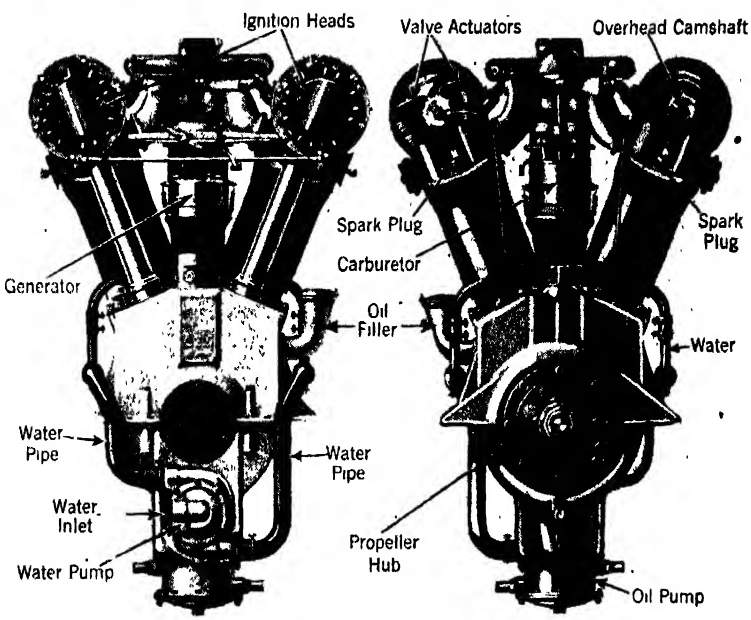


Fig. 160.—Rear and Front Views of Liberty Aviation Engine, an American Development that was Produced in Large Quantities in 1918.

The Liberty Motor.—This very practical power plant was designed for the equipment division of the Signal Corps, United States Army, by a commission of leading engineers working under the direction of Major J. G. Vincent, Chief Engineer of the Packard Motor Car Company and Major E. J. Hall, of the Hall-Scott Motor Car Company shortly after our

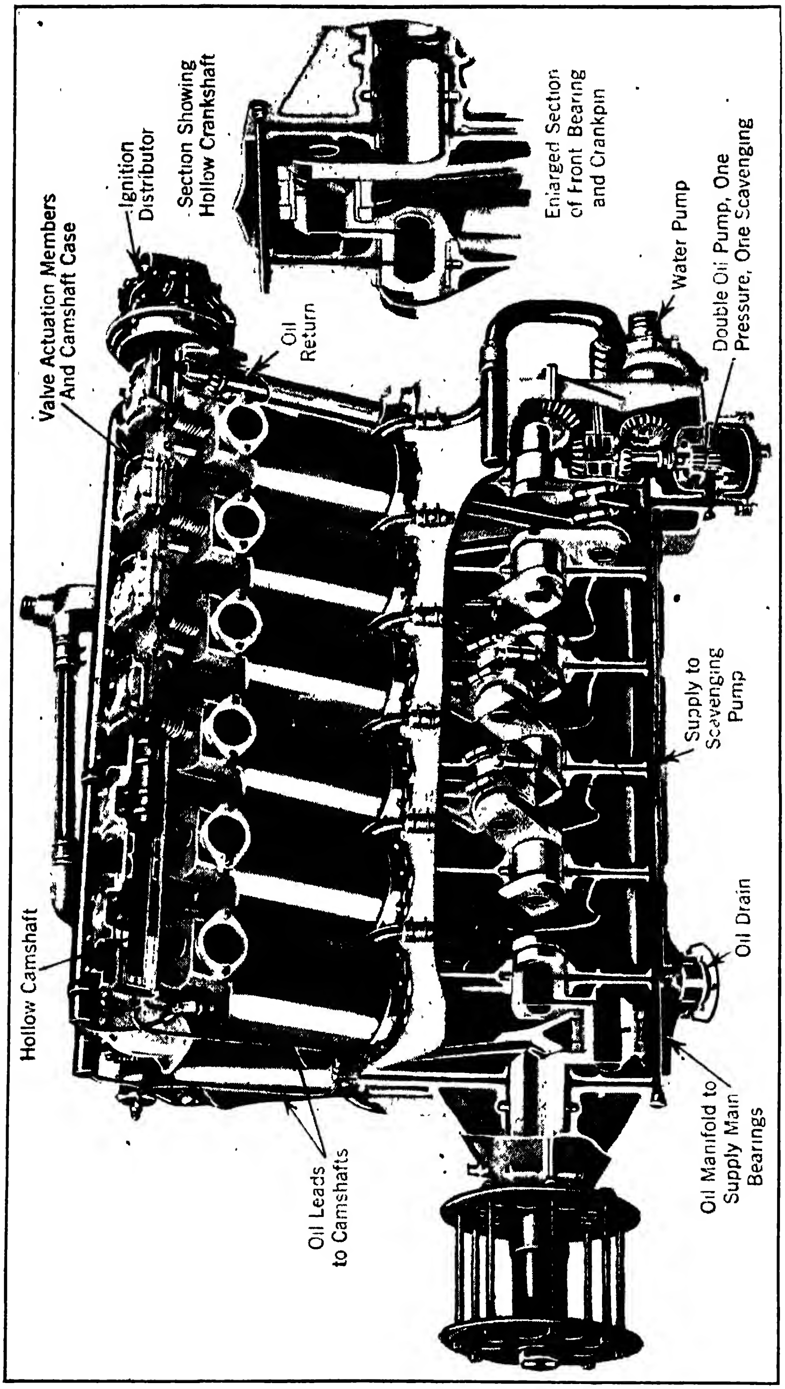


Fig. 161.—Oiling System of Liberty Aviation Engine Operated on Dry Sump Principle, Oil from Pressure Pump Going to Bearings and Camshafts, the Oil Spray Thrown off by Crankshaft Lubricating Interior Walls of Cylinders and Other Parts. Suction Pump Draws all Oil from Crankcase.

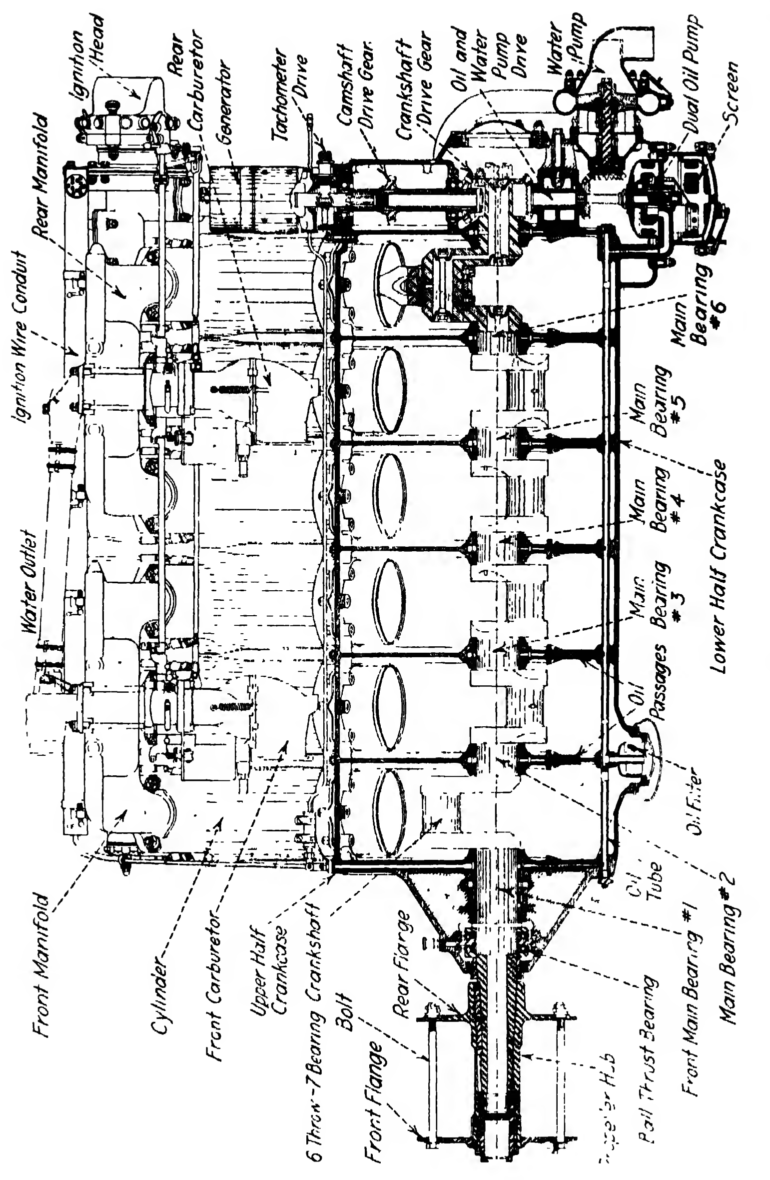


Fig. 162.—Longitudinal Section of Liberty Engine Crankcase Showing Simplicity and Strength of Parts.

entry into the World War. The object was to design a standard engine that could be put into quantity production and built by the same methods that were applied to the production of automobiles in motor car plants. Many thousands of these motors were built to interchangeable standards. There has probably been no motor that was criticized as much or as unjustly as this one. It proved to be a very practical and reliable type in service when compared to contemporary designs of foreign manufacture. Designers of more recently developed types take great pleasure in pulling this design to pieces and showing its weak points when compared to the

newer engines without taking into consideration that if it was not for the experience gained with this and other early engines that the modern highly refined power plants would not have been possible. Such comparisons are not fair, and when viewed in the light of the knowledge that obtained when this engine was first designed; it will always remain an outstanding achievement of American engineering and productive skill. The Liberty engine construction can be understood by referring to illustrations Figs. 160 and 161 which show external views and sectional drawings Figs. 162

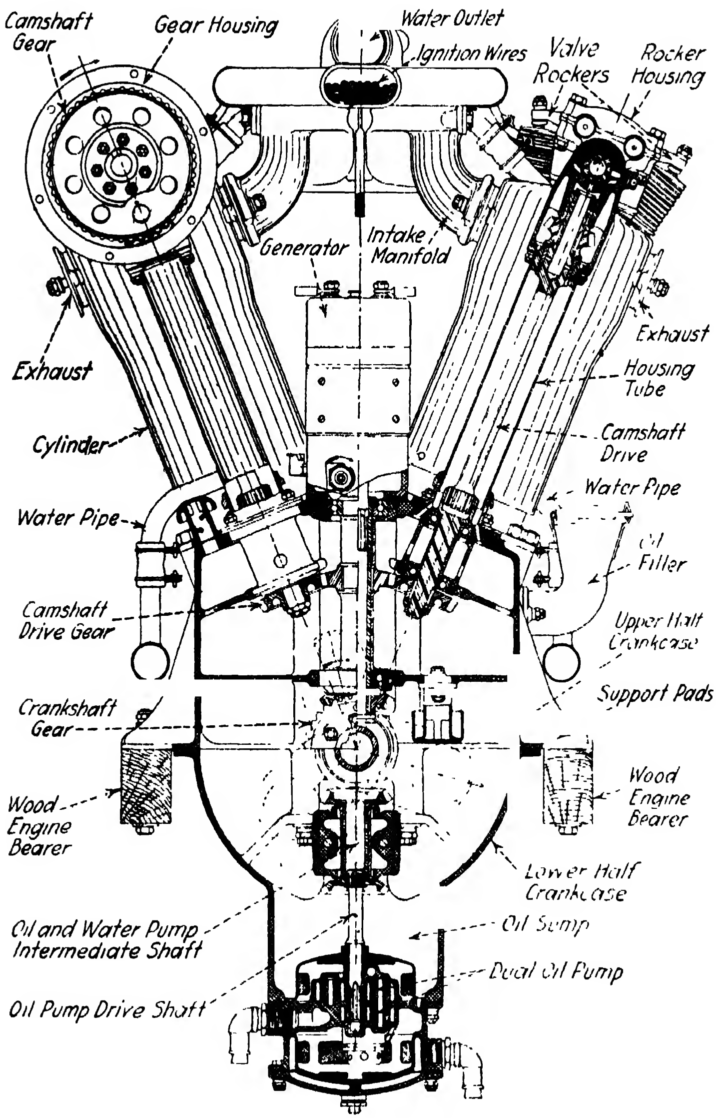


Fig. 163.—End Section of Liberty Engine Crankcase Showing Method of Oil Pump Drive.

to 164 inclusive which show mechanical details. The cylinders are 45 degrees apart. The cylinder bore is 5 inches, the stroke is 7 inches. The cubic displacement is 1,650 cubic inches. The horsepower is 400 at 1,700 r.p.m. The compression ratio is 5.40 to 1 and a mean effective pressure of 113 pounds per square inch is obtained. The engine weighs 806 pounds, as shipped, which gives a dry weight of slightly more than 2 pounds per horsepower.

The water pump water passages and cylinder jackets from face of pump inlet to the face of the water outlet hold 5.5 gallons or 46 pounds of water. The fuel-consumption is .54 pound per horsepower hour or 36 gallons per

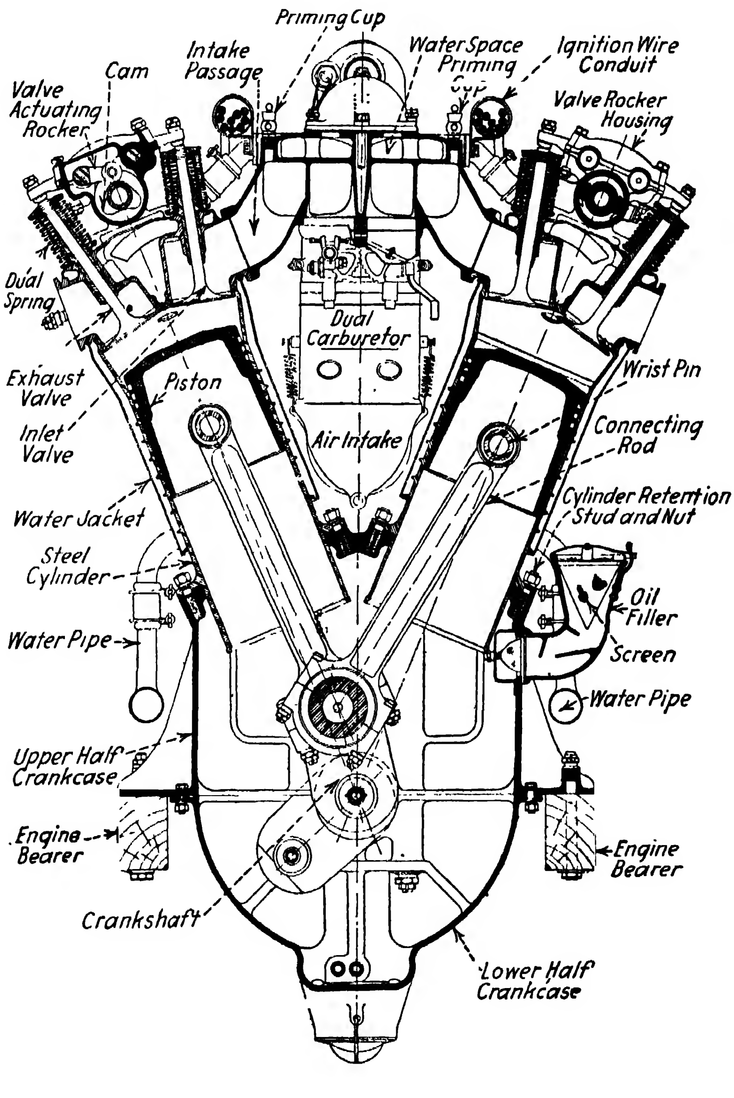


Fig. 164.—Transverse Section through Liberty Engine Showing Cylinder and Piston Construction, Connecting Rod Design and Valve Gear.

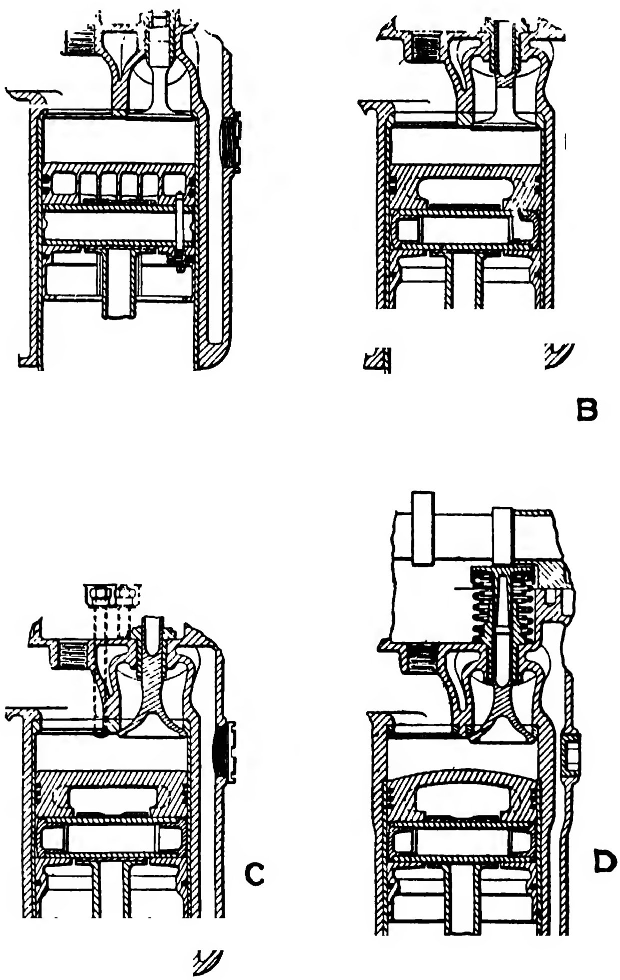
hour with wide open throttle at 1,700 r.p.m. The oil consumption is .03 pounds per horsepower hour or 1.5 gallons per hour with wide open throttle. Sufficient radiator capacity should be provided to hold the water temperature at not to exceed 200 degrees fahrenheit and the water temperature should not be allowed to become lower than 160 degrees fahrenheit or carburetion troubles will result. Ignition is by special Delco battery system. Two Dual Zenith carburetors furnish the mixture.

The valves are actuated by overhead camshafts driven by bevel gearing and vertical shafts. The ignition distributors are mounted at the rear ends of the camshafts. The cylinders are steel with applied and welded sheet steel jackets. The crankcase is aluminum alloy, made in two pieces and is divided on the vertical center line of the crankshaft. The crankshaft is a six-throw seven main bearing type. The connecting rods are of the scissors type, two rods acting on one crankpin.

Pistons are of aluminum alloy, having three wide grooves above the wristpin, each groove being fitted with one ring. Each piston is provided with seven circumferential oil distributing grooves and the piston is relieved around the wristpin bosses. Two forms of pistons are available, a flat top for low compression or training and Navy engines and a domed top for high compression types. The oiling system is a pressure feed dry sump type, as shown at Fig. 161, the internal parts of the cylinder being lubricated by the oil spray thrown off centrifugally by the revolving crankshaft. The general details of construction are so clearly shown in the illustrations that further description seems unnecessary.

Water-Cooled Cylinder Development.—There are two generic types from which modern water-cooled cylinders have been evolved. The development of the cylinders in the Wright aircraft engines is shown in the illustrations at Fig. 165, which have been reproduced from the S. A. E. Journal and which were used in an article by George J. Mead on "Airplane Engine Designing for Reliability." The cylinder shown at A is the original design used in the Hispana-Suiza engine, a pre-war type. This cylinder, in common with that shown at B was used on eight-cylinder V engines. That at B was employed on the Wright E2, a 90 degree V motor having a cylinder displacement of 718 cubic inches. The early cylinder construction consisted of flanged, closed end steel sleeves threaded into an aluminum block. Mr. Mead stated that this engine could not be operated for more than 30 hours at full throttle without valve grinding. The improved cylinder construction shown at C was used on the Wright E3 motor and is similar to the form shown at B and used on the E2 engine except that no threads are used on the sleeve, which is a force shrink fit in the aluminum water jacket block. The sleeves were held in position by studs in the top of the sleeve which passed through the top of the block. This construction was not as good theoretically as the threaded sleeve because not as much surface was in contact with the aluminum jacket wall, but it gave good results in practice. In all these types, the valves seated in the top of the steel sleeve as shown. In the cylinder used in the Wright E4 engines shown at D, the cylinder sleeve is a combination form having threads at the upper end only. It is an open tube wherein it differs from the other types shown.

The combustion chamber is of aluminum alloy and the valves seat into bronze inserts just as in air-cooled engine practice. The cylinder sleeve terminates just above the end of the piston stroke and screws tightly against a shoulder in the aluminum combustion head. This method of construction is known as the "dry sleeve" cylinder and was originally used on Hispano-Suiza engines and patented by the designer, Marc Birkigt, a Swiss engineer associated with a Spanish automobile manufacturer.



—Cross-Section Showing the Cylinder Development in the Wright Aircraft Engine

Fig. 165.—Cross Sections Showing Cylinder Development in Wright Water-Cooled Aircraft Engines. This is Known as "Dry Sleeve" Construction.

Wet Sleeve Construction.—The other method of cylinder construction is called the "wet sleeve" and various cylinders have been experimented with as shown at Fig. 166. That at A is the well known Liberty engine cylinder. The design shown at B is a Curtiss construction in which a closed end sleeve is threaded into an aluminum combustion head block, and the water jacket is completed by another casting bolted to the combustion head. A watertight joint is obtained by a ring of packing material at the bottom of the sleeve. Attention is directed to the heavy section needed around the bolts at the retention flange when aluminum alloy is used instead of steel for the water jacket block. The cylinder shown at C is

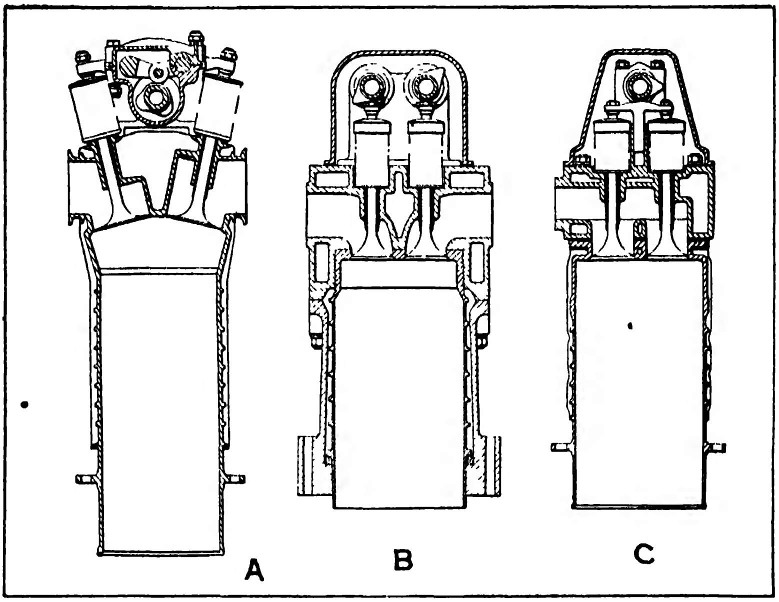


Fig. 166.—Forms of Cylinders Used in Practical Water-Cooled Aircraft Engines. A—Cylinder of Liberty Engine. B—Curtiss Wet Sleeve Construction. C—Packard Cylinder Construction.

the final type evolved as a result of much study and practical testing by the Packard engineers. Each block is composed of six individual cylinders attached to a single aluminum casting that is termed the valve-housing. The individual cylinder is composed of a drawn-steel sleeve welded to a forged combustion chamber head machined completely, and having a head-plate and a sheet-metal water jacket welded into place. Each cylinder is provided with four valves, short valve-ports being formed integral with the cylinder. These valve-ports are accurately hollow-milled on their outer surfaces; and the head-plate is bored so as to form a pressfit over the valve-ports, the plate seating on shoulders so as to provide about ⅜ inch water-space above the combustion chamber. The cylinder head is provided with five bosses into which are screwed long studs for supporting the valve-housing. The spark plug bosses are formed integral with the combustion chamber. The cylinder retention flange is so placed that the cylinders project into the crankcase. This method of construction serves to add depth

to the crankcase with a considerable gain in rigidity. Another incidental advantage accruing from this construction is that the engine can be run successfully in an inverted position, the advantages of which have been previously considered. Other advantages of individual-cylinder construction are ease of manufacture, ability to install the largest possible valves while maintaining adequate water-circulation around all the valve seats and, finally, a cylinder-spacing arrangement closer, it is believed, than is possible with any other construction.

The aluminum valve-housing is bolted to the six cylinders to form a cylinder block; and this block remains assembled in this fashion throughout all the usual assembling and disassembling operations, although, if necessary, an individual cylinder can be replaced at any time with the mini-

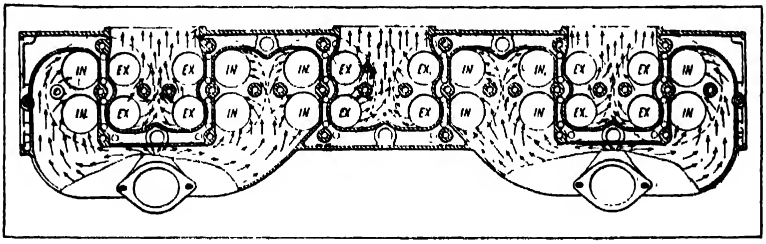


Fig. 167.—Sectional View of Packard Valve Housing Showing Location and Porting of Valves, Four Valves Being Used for Each Cylinder.

mum of delay. This method of cylinder construction was described by L. M. Woolson, M. S. A. E. in a paper read before the Society and a sectional view of this valve-housing showing intake, exhaust and water passages and also showing how large and free passages are secured by Siamesing four valves into one port is clearly shown at Fig. 167.

The valve-housing is an aluminum casting machined on all surfaces. It is used interchangeably on the right and the left banks and performs the following functions:

(1) Distributes the mixture to the six cylinders from the two carburetor cross-header manifold connections.
(2) Forms the exhaust-passages, each two adjacent cylinders having their two pairs of exhaust ports siamesed into a single exhaust outlet.
(3) Collects the water circulated through each cylinder-jacket and delivers it through a single outlet at the front of the engine.
(4) Supports the camshaft-bearing pedestals and the valve stem guides.

The diagram in Fig. 167 shows the intake, exhaust and water passages in the valve-housing, the siamesing of four valves into one port being largely responsible for the large and free passages that are allowed by this construction. The longitudinal section through Packard aircraft engine Model 2A 1,500 direct at Fig. 168 shows how the valve-housing is installed between the camshaft housing and the cylinder assembly and also shows how closely the cylinders may be placed.

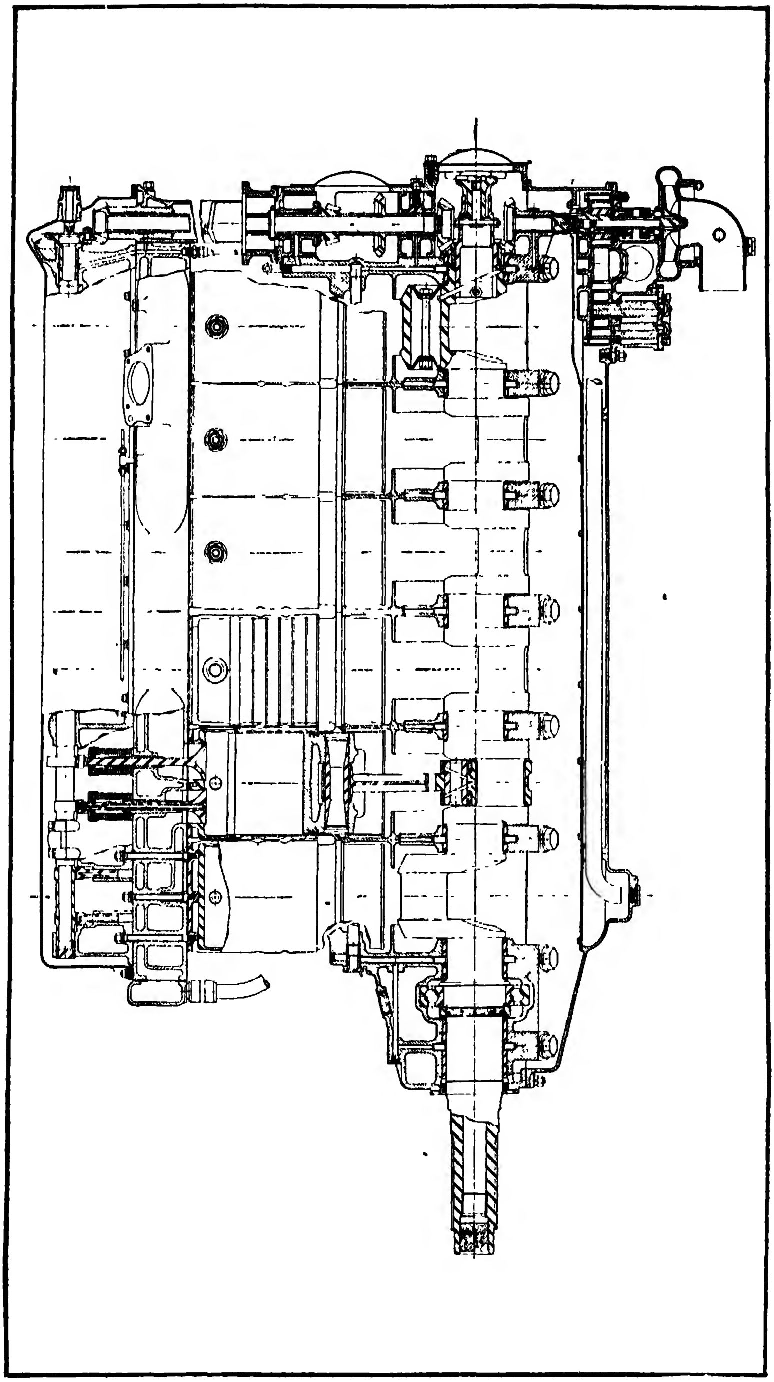


Fig. 168.—Longitudinal Section through Packard Aircraft Engine Model 2A—1500 Direct Drive, Showing Cylinder Construction and Method of Valve Actuation by Overhead Shaft.

Water is led into the individual cylinders from a manifold connected to short pipes welded to the jacket at the lower end. The water delivery from the cylinder is through a series of holes drilled in the top plate and arranged radially about the exhaust ports so as to ensure that local steam pockets will not be formed above the exhaust valve seats. A single copper-asbestos gasket is used between the individual cylinders and the valve-housing, this gasket, of course, not being subjected to gas pressure as in the conventional automobile detachable-head gasket, but merely serving as a water-seal to prevent leaks between the inlet and the exhaust passages.

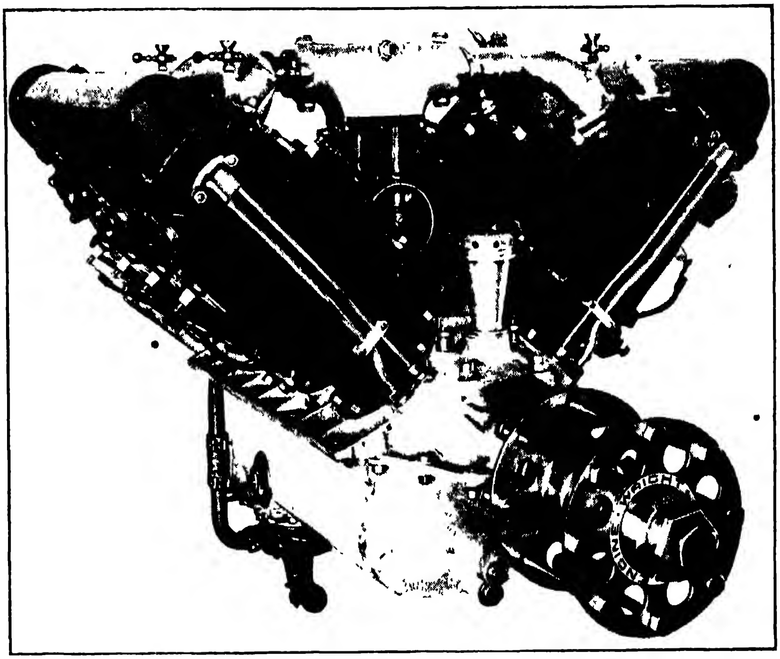


Fig. 169.—Wright Hispano-Suiza Aviation Engine, Model E 2.

Wright Water-Cooled Engines.—Improvements made by the Wright engineers have produced an aircraft engine that will operate for longer periods at higher mean effective pressures than any other type of internal combustion engine. Several types weighing less than 2½ pounds per horsepower have run for periods of from 200 to 300 hours with but little attention. The Wright E-4, with the same crankcase assembly, the cylinders only being changed, ran for 572 hours without attention of any kind. Compared with the original Model A, built 10 years ago, the present engine with approximately the same weight and same displacement develops one-third more power, operates at 24 per cent more speed and has 3,000 per cent greater durability.

During the war, exhaust valves, connecting rod big end bearings and spark plugs gave the most trouble. In cylinder construction three difficulties presented themselves: (*a*) the valves warped and burned, (*b*) the valve seats did not remain true and (*c*) in long runs the valves hammered into

the seats so that the tappet clearance was lost and the valves were held open. The present type of Wright cylinder as shown at Fig. 165 D and the use of tulip head silchrome steel valves have greatly reduced valve troubles. Refinement of details of the 1,947 cubic inches 60 degree V-type 12-cylinder Wright T-3 engine has enabled it to be used satisfactorily at speeds greater than 2,200 r.p.m. and to develop 750 horsepower with approximately 140 pounds mean-effective pressure at 20 per cent less weight per horsepower than that of the original engine.

The Wright E2 engine, shown at Fig. 169 is no longer in production but it was a popular type for some years. This engine has practically all of the characteristics of the Hispano-Suiza as previously described. The cylinder construction is shown at Fig. 165 A. The improved and refined

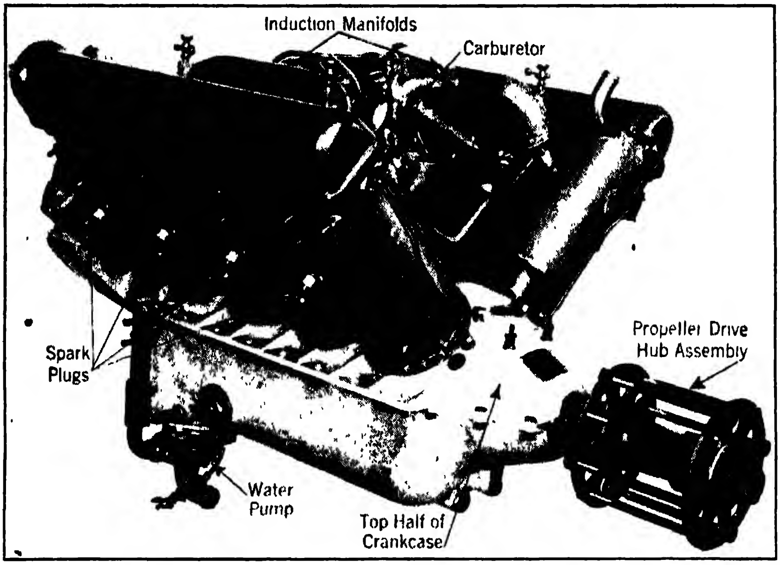


Fig. 170.—Wright 200 Horsepower Aviation Engine, Model E-4 has Eight Water-Cooled Cylinders in Two Blocks of Four.

Wright E4 shown at Figs. 170, 171 and 172 is the type that has been operated for 310 hours with one cylinder assembly, or long enough to have driven an airplane 31,000 miles without overhauling. After a new set of cylinders had been fitted, the other parts were run an additional amount so that the equivalent of 57,200 miles operation was obtained with only minor external adjustments. The old Model A engines developed a maximum of 175 horsepower at 1,800 r.p.m. whereas the latest models of the same type develops a maximum of 285 horsepower at 2,300 r.p.m. The bore of the E4 cylinders is 4,710 inches, the stroke is 5,110 inches and the total displacement is 718 cubic inches. This engine is no longer in production, all demands for this horsepower being supplied with radial air-cooled engines.

The Wright Tornado or T3A engine shown at Fig. 173 is the latest development of the water-cooled types and uses the type of cylinder shown

at Fig. 165 D. It may be obtained in either the direct drive or geared forms. The Wright Tornado engine is one of the most powerful aviation engines ever put into large series production. It is guaranteed to deliver 650 horsepower (high compression 6.5:1) for service and considerably higher for special work as actual tests have shown that it is capable of delivering 745 horsepower for several hours at a time. The rating with low compression (5.3:1) is 600 horsepower at 2,000 r.p.m. It has a very light weight per horsepower. At 650 horsepower the weight per horsepower is only 1.79 pounds, and at 745 horsepower it is as low as 1.57 pounds per horsepower. This low weight, 1,166 pounds (530 k.g.) has not been accomplished by sacrificing durability. Repeated trials in actual hard service show the fuel-consumption to be as low as .48 pounds per horsepower hour. The fuel-consumption is exceptionally good through all ranges from full throttle to low cruising speeds. On propeller load, .445 pounds per horsepower hour is often reached at cruising speeds.

General Specifications

Wright Tornado, T-3 Aviation Engine

Bore—5.75 inches.
Stroke—6.25 inches.
Number of Cylinders—12.
Displacement—1,947 cubic inches.
Compression Ratios—5.3:1 (low) and 6.5:1 (high).
Guaranteed Powers—650 horsepower at 2,000 r.p.m. (High compression).
600 horsepower at 2,000 r.p.m. (Low compression).
Average Powers—680 horsepower at 2,000 r.p.m. (High compression).
625 horsepower at 2,000 r.p.m. (Low compression).
***Guaranteed Fuel-Consumption**—.52 pounds per horsepower per hour.
***Guaranteed Oil Consumption**—.025 pounds per horsepower per hour.
Dry Weight of Engine Complete Ready to Run, with carburetors, dual running magnetos, pumps, propeller hub, exhaust flanges, etc., etc., but without hand turning gear and fuel pump—1,166 pounds.
Weight of Water in Engine—59 pounds.
Weight of Hand Turning Gear (with starting magneto)—25 pounds. Hand Crank 3.2 pounds.
Weight of Fuel Pump—2.5 pounds.
Direction of Rotation—Anti-clockwise looking at the propeller hub.
Standard Equipment—All necessary equipment for the operation of the engine is supplied, including drive **only** for two Nelson gun synchronizers, one tachometer, electric generator in the Vee of the engine, a Wright engine driven fuel pump, and Wright hand turning gear with starting magneto.
Special Equipment—Offset propeller hubs can also be furnished, which provide 8 inches between the forward cylinders and the back flange of the propeller hub. Propeller hubs can be supplied for 2 or 3 bladed metal propellers. Propeller reduction gearing can be supplied. Inertia starters can be supplied and attached. Adapter for distant drive fuel pump can be supplied. Wright oil temperature control system either

manually operated or automatic can be furnished, also Wright fuel strainers attached to the engines. This special equipment is at an extra price and not included in quotations unless specifically mentioned.

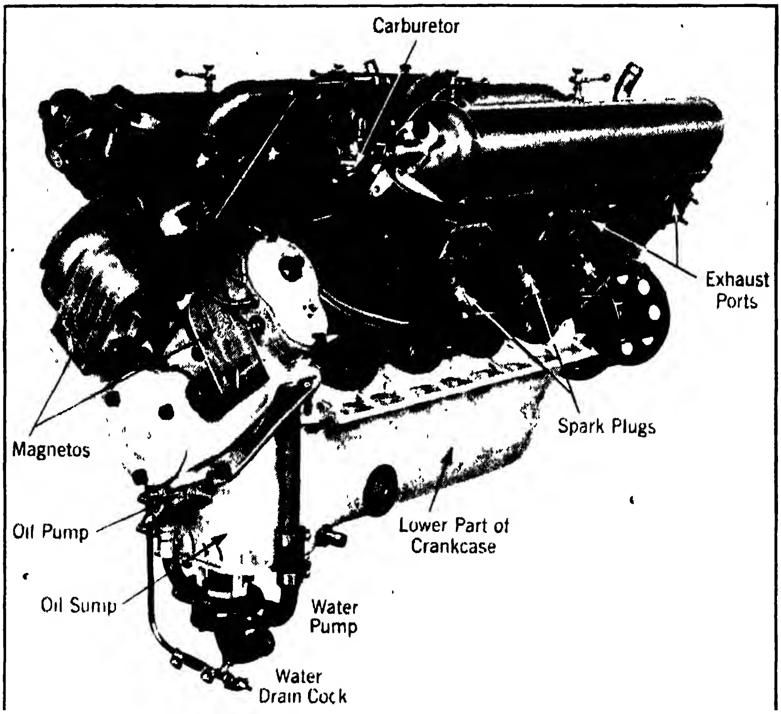


Fig. 171.—Wright "Tempest" E 4 Water-Cooled Engine Viewed from the Rear Showing Magneto Mounting and Water Pump Location.

Packard Aircraft Engines.—Two engines of 500 and 800 horsepower respectively have been recently developed by the Packard Motor Car Company for aircraft service. When these engines are compared with previous types they are found to be more compact and to produce more power per pound of weight. When each is operated at its rated speed, the Model 1,500 engine shown at Fig. 174 develops 100 horsepower more than the Liberty while weighing 140 pounds less, and the Model 2,500 engine develops 250 horsepower more than its predecessor, the Model 2,025, with a decrease in weight of 75 pounds. The Packard aircraft engines were described by L. M. Woolson, M. S. A. E. at a meeting of the Society and the following description is taken from the S. A. E. Journal.

These improvements have been made possible largely because of a new type of cylinder construction, original studies with regard to the loads that can be carried by bearings, reduction of the weight of the crankshaft while at the same time strengthening it, and the compacting and lightening of the timing and accessory-drive layout. Other improvements were made in the lubricating system and in the design of the valve-gear and springs.

The novel cylinder construction which has been previously described enables the cylinders to be spaced closely together and the weight of the whole engine to be diminished. Other advantages incorporated into the design include water circulation in close contact with the heated surfaces, the use of a steel cylinder barrel as a wearing surface that carries the explosion loads down to the crankcase, the locating of the hold-down flange some distance from the end of the cylinder barrel so that the ends of the barrels of the cylinders of the two banks can practically be allowed to touch

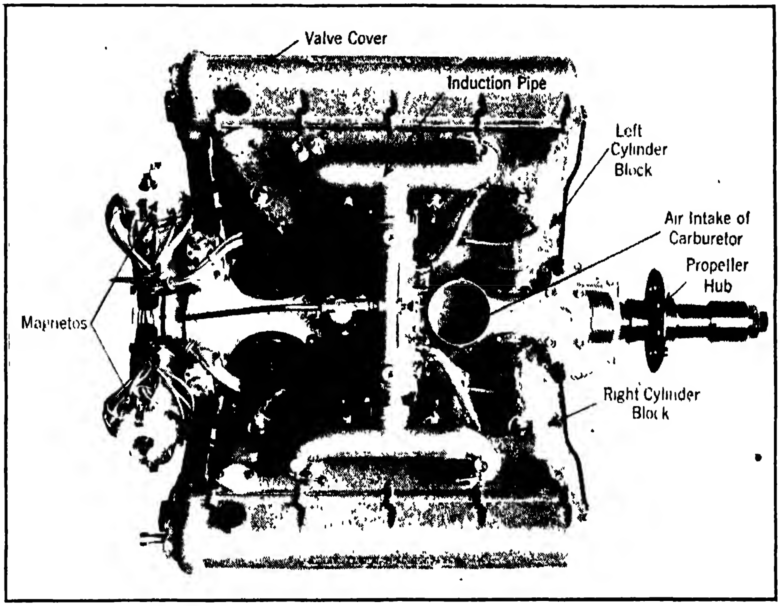


Fig. 172.—Top View of Wright "Tempest" E-4 Water-Cooled Engine Showing Carburetor and Induction Manifolding.

inside the crankcase and the engine can be run in an inverted position. Mr. Woolson stated that the complete weight of the Model 1,500 cylinder is but 9.5 pounds and the cylinder develops nearly 50 horsepower. The weight of the Model 2,500 cylinder is 15.2 pounds and the cylinder develops 70 horsepower. The front end view of the Model 2A 1,500 inverted engine is shown at Fig. 175 A and a side view at Fig. 175 B.

Still other features comprise improved types of valve-housing and valve-gear layout; positive cooling of the exhaust valve by oil pumped through it; a special type of multiple cluster small diameter piano wire valve spring; simplicity in the grouping of the accessories; a special type of magneto having a single magnetic circuit and two independent electrical circuits, either one of which will fire all 12 cylinders; the possibility of replacing magneto ignition with battery ignition by substituting a generator for the magneto but without other change to the engine or to the wiring between the distributors and the spark plugs; the use of very short comparatively light rugged slipper-type pistons; and the ability to use either direct drive or gear reductions. In applying these facts to commercial aviation, these

comparative performances mean that the new engines can carry double the pay-load over the same distance or the same pay-load 2¼ times as far as could their progenitors.

The pistons of both the Model 1,500 and the Model 2,500 engines are of special interest in that they are of the slipper-type and are very short and comparatively light, although of rugged construction. The Model 1,500 piston is 3 11/32 inches long and weighs 2.94 pounds; the Model 2,500 piston is 3 15/16 inches long and weighs 4.47 pounds, bare. The smaller piston is 5⅜ inches in diameter and has only 90 per cent of the weight of the Liberty piston although having 15 per cent more area; the larger piston is 6⅜ inches in diameter and has 63 per cent of the weight of the Shenandoah engine piston although having only 9 per cent less area than the latter. The lengths of these new pistons were established after a series of tests in which the length of the skirt was gradually diminished.

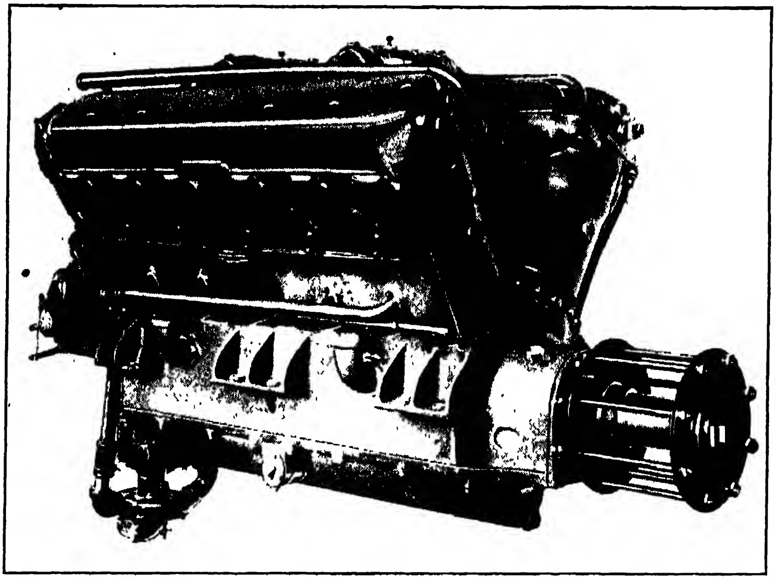


Fig. 173.—The Wright "Tornado" Model T 3A Engine is a Twelve Cylinder V Type and will Deliver 650 Horsepower at 2000 Revolutions Per Minute.

As a result of investigating the relation of bearing materials to allowable speeds and loads, it was ascertained that failures of aircraft bearings rarely occur because of lack of lubrication or of wear but are caused by fatigue of the babbitt lining produced by minute flexing of the back of the bearing. Tests showed that the limitations of the bearings could be raised provided they could be prevented from flexing under load and ample force-feed lubrication were provided. The PV values of the bearing loads adopted, as compared with those of the Liberty engine, are: for the crankpin, 18,520 pounds per square inch as against 13,200; for the center bearing, 35,000 as against 22,650; and for the intermediate bearing, 27,000 as against 14,000. The critical speed of vibration of the Packard crankshaft is 64 per cent higher than that of the Liberty; it is also twice as stiff as well as weighing

30 per cent less, a feature accomplished by the use of journals having comparatively large outside diameters but bored out through their centers.

The crankcases of both engines are of particularly rugged design, great depth being obtained partly because of the design of the cylinder and partly because of the arrangement of the main bearings. The eight main bearings as shown at Fig. 176 which shows a longitudinal section of the inverted 2A 1,500 engine are of steel-backed babbitt construction, the upper half

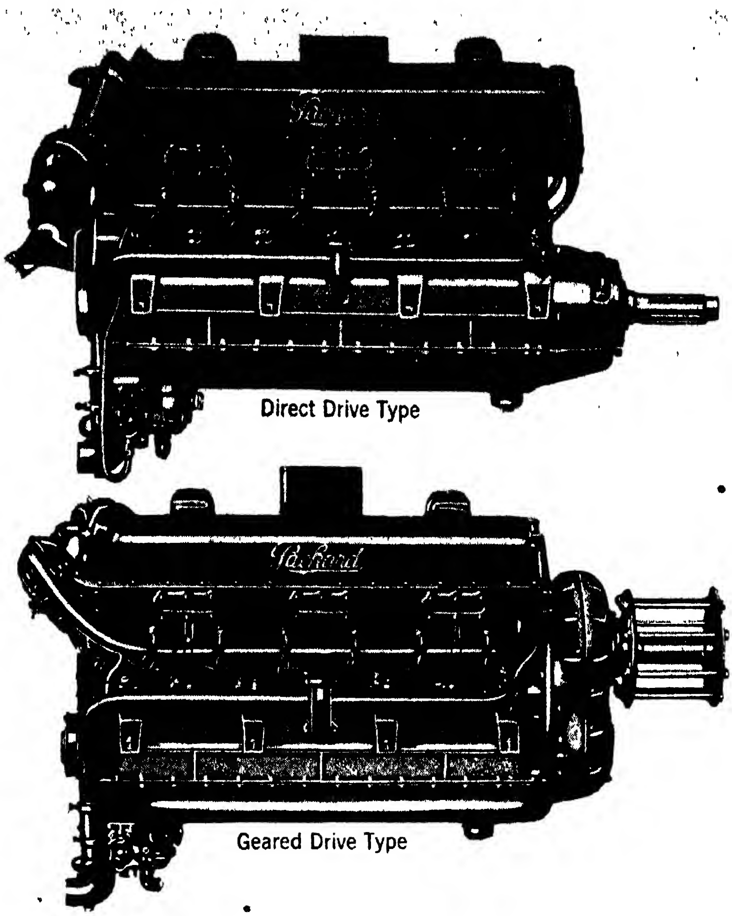


Fig. 174.—Packard Model 2A 1500 Aircraft Engines. Direct Drive at Top, Geared Drive Shown below it.

being doweled to the crankcase and the lower half to the forged duralumin bearing caps that are accurately fitted in longitudinally machined ways in the transverse webs of the crankcase. With this construction, in a V-type engine, the main bearing bolts are relieved of bending stresses imposed by the explosion loads. The thrust bearing is of the deep groove radial ball bearing type and is located between two plain bearings in the front bearing cap.

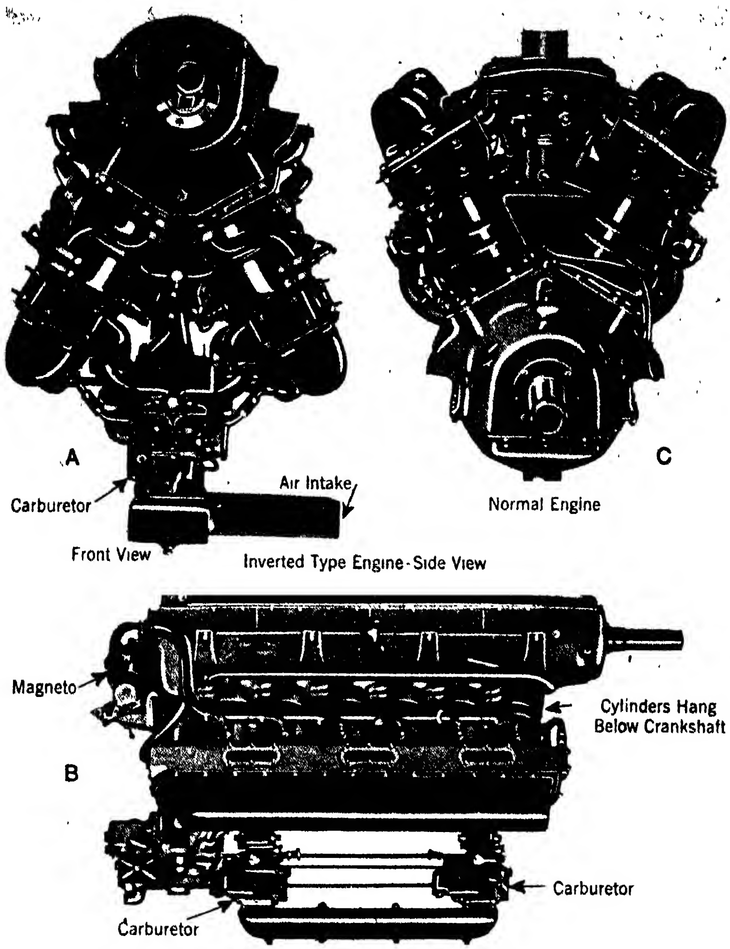


Fig. 175.—Views of Packard 2A 1500 Aircraft Engine of the Inverted Type Shown at A and B. Compare Carburetor Location with that Shown at C, which is Front End of the Same Engine Used in the Conventional Manner.

The lower half of the crankcase is an aluminum stamping that serves merely as an oil-pan and supports the combined pump unit by a generous flange.

The propeller hub is of the taper-fit type on the smaller engine and carries a forged-duralumin loose flange which, it should be noted, is not keyed or otherwise located on the propeller hub, a construction that has proved perfectly satisfactory in flight tests as well as in overload propeller-whirling tests. On the larger engines a splined hub with split centering cones is used.

Although both the 500 and the 800 horsepower engines were originally intended for direct drive service, both have been built for use with gears, the gear reduction forming a separate unit bolted to a special crankcase flange. The gear reductions have been designed and built by the Allison

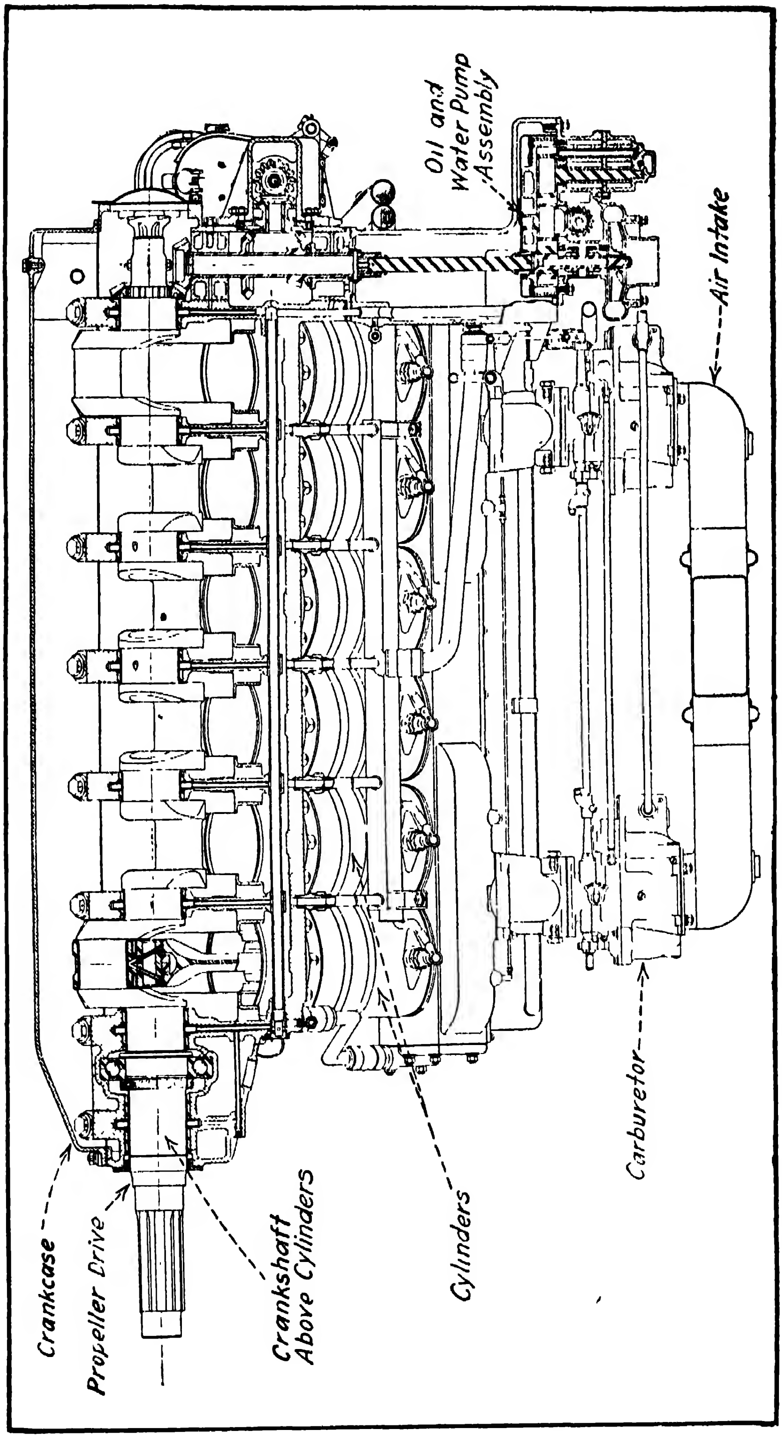


Fig. 176.—Longitudinal Section Through Packard Aircraft Engine Model 2A 1500 Inverted.

Engineering Company of Indianapolis. They are of the spur-gear single reduction type and are entirely self-contained. A noteworthy feature is the employment of a shock-absorbing drive between the crankshaft and the pinion that has proved very successful in eliminating the gear trouble resulting from impact loading. Fig. 177 A shows the sectional side view and Fig. 177 B the side view of the 800 horsepower geared engine. These gear reductions give a two-to-one reduction to the propeller-shaft that

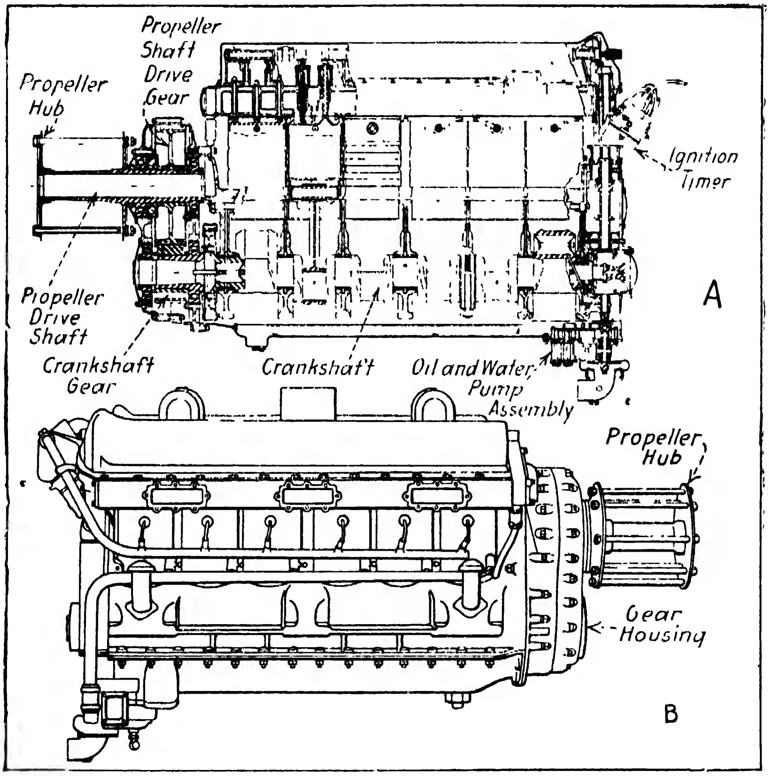


Fig. 177.—Longitudinal Section of Packard Aircraft Engine Model 2A 2500 Shown at A Depicts Important Parts, Especially the Propeller Drive Gearing. The External Appearance of the Same Engine is Shown at B. This Engine Develops 800 Horsepower.

has been found to be particularly desirable for load-carrying airplanes of moderate speed. In addition to providing improved propeller efficiency, these geared engines lend themselves particularly well to a streamline installation; and, in this manner, improved propeller efficiency and decreased resistance combine to offer important advantages in airplane performance.

The 500 horsepower engine has also been built in the inverted type and, as mentioned previously, an inverted engine has many advantages for aircraft use. It is entirely possible that the future will see the inverted engine as one of the standard types. A side view of the inverted Model 1,500

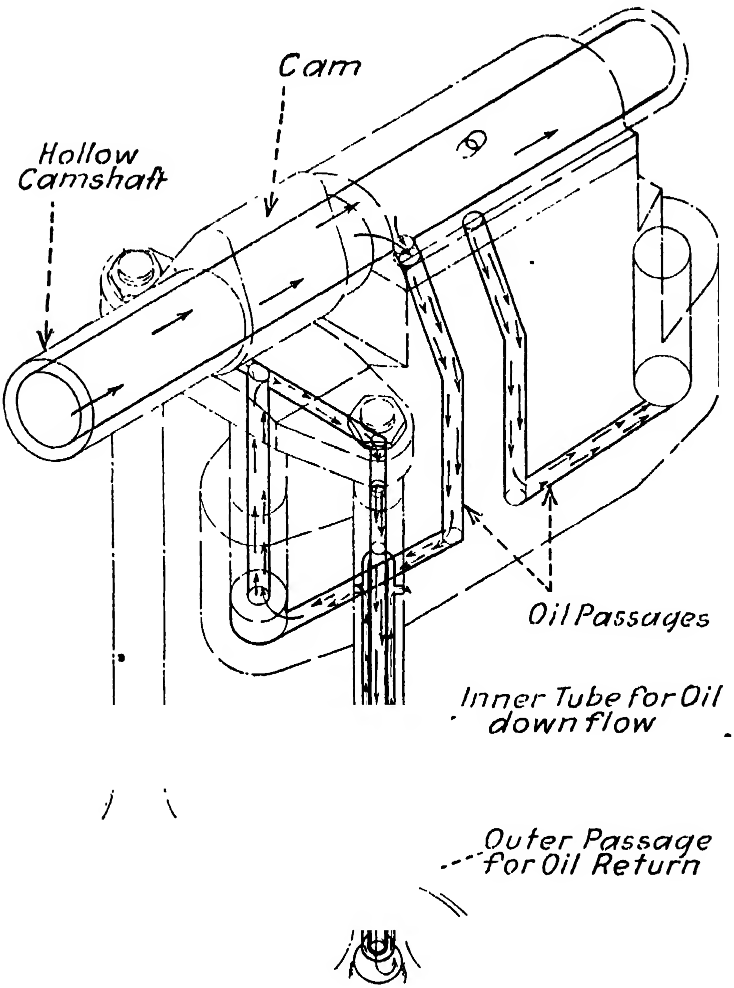


Fig. 178.—Diagram Showing Oil Circulation through Exhaust Valves on Packard Aircraft Engines, Models 2A 1500 and 2A 2500 to Keep Valves Cool.

engine is shown in Fig. 175 B, and a front view in Fig. 175 A. A longitudinal sectional view is shown at Fig. 176.

Packard Oil-Cooled Valves.—One of the important features in the design of large aircraft engines is the manner of valve cooling, especially the exhaust valves. In the Packard engines this is accomplished by circulating oil through the valve stem as shown at Fig. 178. Means for cooling the exhaust valves by the circulation of oil are provided by suitably drilled passages in the camshaft bearings adjacent to the exhaust cams, this feature of the construction being shown diagrammatically in Fig. 9. The camshaft is hollow and is supplied with oil under pressure through a con-

tinuous metering groove in the rear bearing. In the camshaft journal next to each exhaust cam is drilled a hole opposite to the nose of the corresponding exhaust cam. This hole registers with a vertical passage in the camshaft bearing pedestal when the cam is at its highest point and the exhaust valves consequently are closed. The oil flows through this passage to the bottom of the cam-follower guide, which forms a closed end cylinder, and the space underneath the cam-follower is thus filled with oil. The camshaft in revolving cuts off communication with this passage and, when the cam-follower is depressed by the cam, the oil can escape only by being forced through the hollow cam-follower stem and the horizontally drilled passages

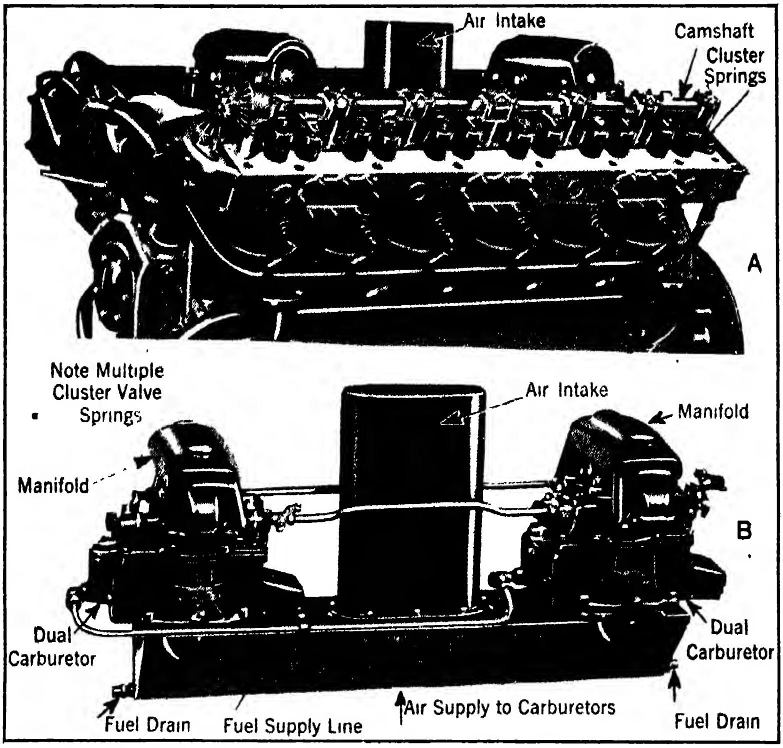


Fig. 179.—View at A Shows Packard Valve Gear with Overhead Camshaft and Multiple Cluster Springs. B Shows Carburetor Joined to Common Air Intake Castings with Vertical Intake Stack. Each Carburetor Carries an Induction Pipe by which it is Coupled to Valve Housings.

leading out through the drilled tappets into the exhaust valve stems. The latter are drilled throughout their entire length, the lower end of the hole in the valve-head being closed by a screwed-in plug. A small steel tube is welded to this plug and is centered in a counterbore at the upper end of the valve stem. The oil is forced down through the tube and out at the bottom through horizontal holes, thus cooling the head of the valve. The oil is discharged through the annular space between the tube and inner wall of the valve stem and out of the valve-housing through horizontal holes drilled through the upper end of the valve stem just below the counterbore.

As a result of this oil-cooling the exhaust valves operate at very low temperatures and the valve seat is maintained in good condition for long periods.

Packard Multiple Cluster Valve Springs.—The valve springs are worthy of special note. These are of the multiple cluster type and consist of a group of small diameter piano wire springs arranged in a planetary fashion around the valve stem. In the Model 1,500 engine, 7 of these springs and, in the Model 2,500 engine, 10 springs are used with each valve. The individual springs are located over tubular guides that are welded to a lower fixed washer; the upper ends of the springs engage in an annular groove formed in the movable spring washer. One of the banks of cylinders of the Model 2A 2,500 engine is shown at Fig. 179 A with the valve-housing cover removed to show the multiple springs.

Several advantages accrue from this construction, which may justifiably be termed indestructible. The most important point, perhaps, is the least obvious, namely, that which relates to the natural period of vibration of the small springs. Other advantages result from the increased factor of safety in numbers, since any valve will continue to function even though several of the springs may be broken. Furthermore, the reciprocating weight, represented by the upper washer and one-half the weight of the springs, is reduced, as compared with the conventional construction, and, finally, the physical properties of the small gauge piano wire are generally superior to those of springs heat-treated after forming.

Valve spring failures have always been prevalent to a certain extent in aircraft engines; and these failures at times lead to disastrous results with overhead-valve engines for the valve may drop into the combustion chamber and, consequently, wreck the piston and the combustion chamber head. For some time, these failures were regarded as not being preventable, the cause being attributed to fatigue and to minute imperfections in the material. It is clearly proved that the basic seat of the trouble lies in a resonance effect between the natural vibrations of the spring and the forced oscillations of the engine. These latter oscillations are brought about by the firing impulses.

The Packard engineers had noted that, in very high-speed six-cylinder engines, valve spring breakages were frequently encountered at speeds in excess of 4,000 r.p.m.; in 12-cylinder engines the limiting speed appeared to be above 2,000 r.p.m.; and in some 18-cylinder engines frequent valve spring failures occurred at very moderate speeds, certainly not exceeding 1,600 r.p.m. Naturally, the valve springs in each case were of somewhat different design from the others but the variations were not of sufficient magnitude to refute the statement that the critical engine speed at which valve spring failures assumed alarming proportions was inversely proportional to the number of cylinders or of the firing impulses.

The fact that the small springs have been immune from failure, after a great many prolonged tests with high-speed engines, goes a long way toward substantiating the claim that valve spring breakage in the past has been brought about by synchronized vibrations.

As will be seen from the illustrations, the engines are somewhat the same in general appearance and design. The Model 2A 1,500 is made in

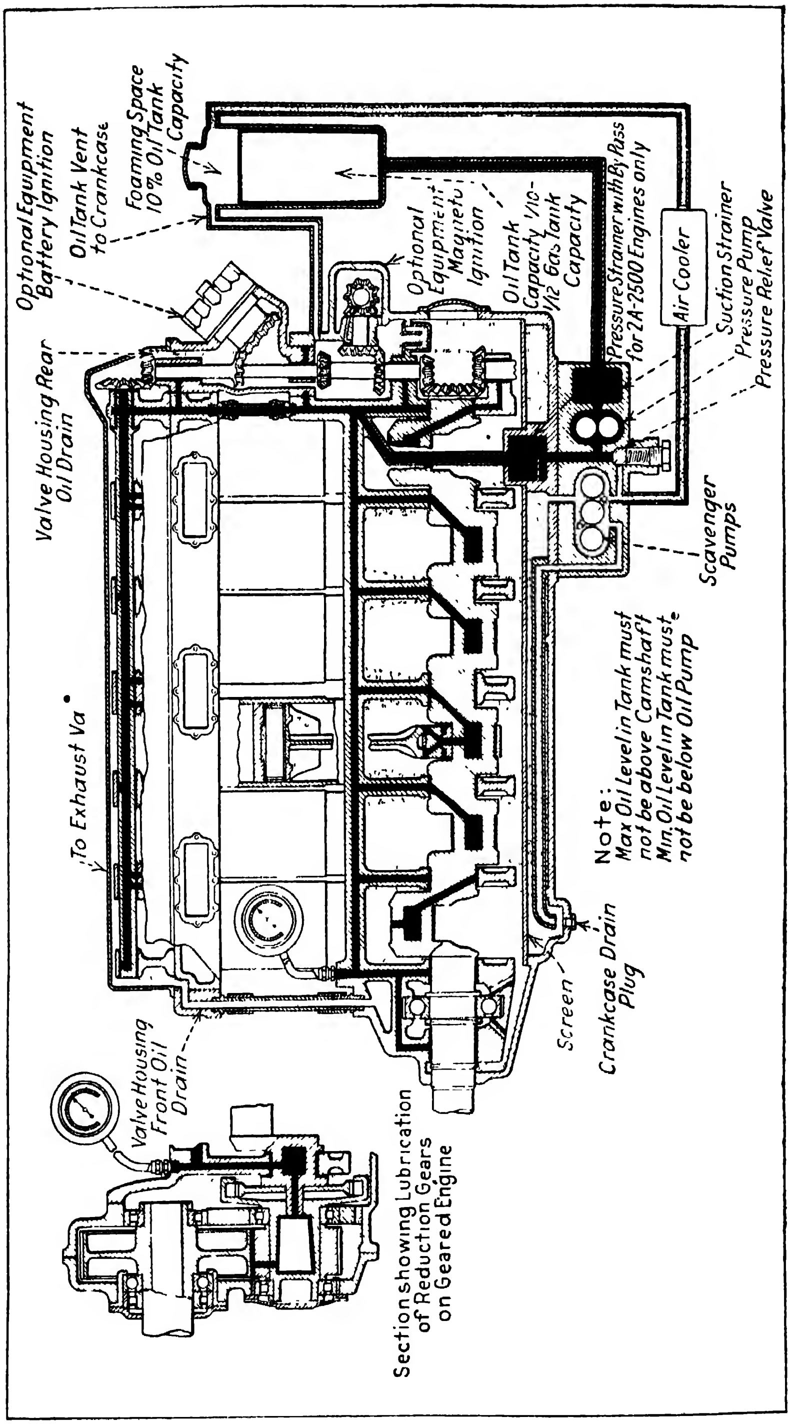


Fig. 180.—Lubricating Chart of Packard Aircraft Engines Models. 2A 1500 and 2A 2500 Shows Latest Practice in Aviation Engine Oiling Systems.

direct, geared and inverted forms. The Model 2A 2,500 is made in the direct drive and geared forms. The rating of the smaller engine is 525 b.hp. at 2,100 r.p.m. and 600 b.hp. at 2,500 r.p.m. The larger engine develops 800 b.hp. at 2,000 r.p.m. Both engines are of the twelve-cylinder V-type with cylinders 60 degrees apart. The bore of the 2A 1,500 engine is 5⅜ inches, the stroke 5½ inches and the total piston displacement is 1,530.4 cubic inches. Three compression volume ratios may be obtained, depending upon the use the engine is to receive. These are 5.1 to 1, 5.5 to 1 and 6 to 1. The direct drive 2A 1,500 weighs 780 pounds with propeller hub

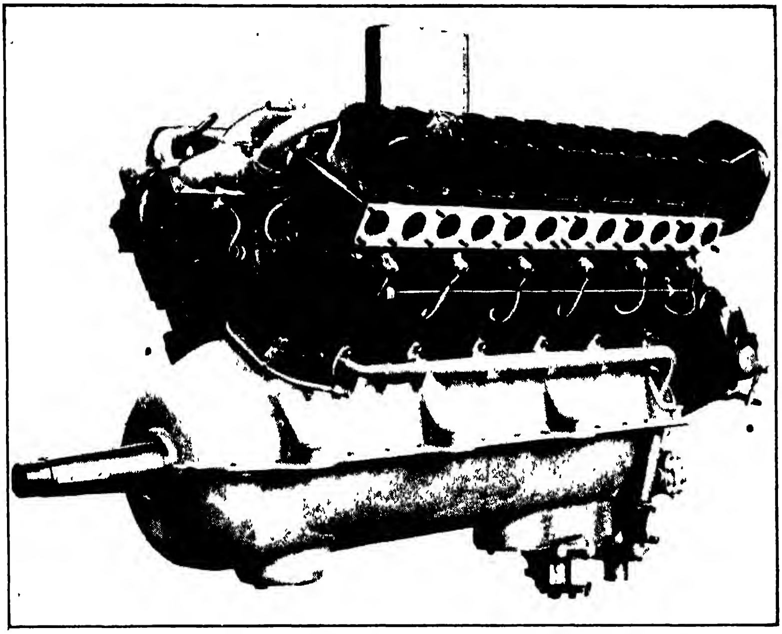


Fig. 181.—Curtiss D 12 Water-Cooled Engine is a Light, Compact and Powerful Twelve Cylinder Form. This is a Three-Quarter Front View.

assembly, the geared form weighs 880 pounds. Carburetion is by two special Stromberg Duplex carburetors mounted on a common air intake fitting as shown at Fig. 179 B.

The 2A 2,500 engine has cylinders of 6⅜ inch bore and 6½ inch stroke which gives it a total piston displacement of 2,539.55 cubic inches. Two compression ratios are provided 5.1 to 1 or 5.7 to 1. The direct drive engine weighs about 1,200 pounds with magneto ignition and propeller hub. The geared form weighs 1,380 pounds. The engines may be obtained with Scintilla magneto ignition or with Delco battery and generator ignition.

Packard Lubricating System.—The lubricating system of the Packard aircraft engines has been very carefully worked out and is practically the same in both engine models. The diagram at Fig. 180 shows the flow of oil very clearly. The oil is drawn from the oil tank which should be about one-tenth the capacity of the fuel tank through a suction strainer by a gear form of pressure pump. Part of the oil goes to the main bearings and

a part goes to the overhead camshafts and through the exhaust valve stems. Part of the overflow from the camshaft returns to the sump through the timing gear shaft housings and part returns to the thrust bearing and main bearing assembly at the propeller end of the engine. The oil thrown off centrifugally by the revolving crankshaft oils the cylinders and pistons. All oil accumulating in the sump is drawn out of the engine base by scavenger pumps and forced through an oil-cooler and back to the foaming space in the lubricating oil tank.

Curtiss Aviation Engines of Recent Design.—The Curtiss aircraft engines have been widely used and favorably known for many years and many record endurance, altitude and speed flights have been made with these motors. The popular and generally used OX-5 series of wartime were succeeded by the K6 and K12 engines, the former having six cylinders and

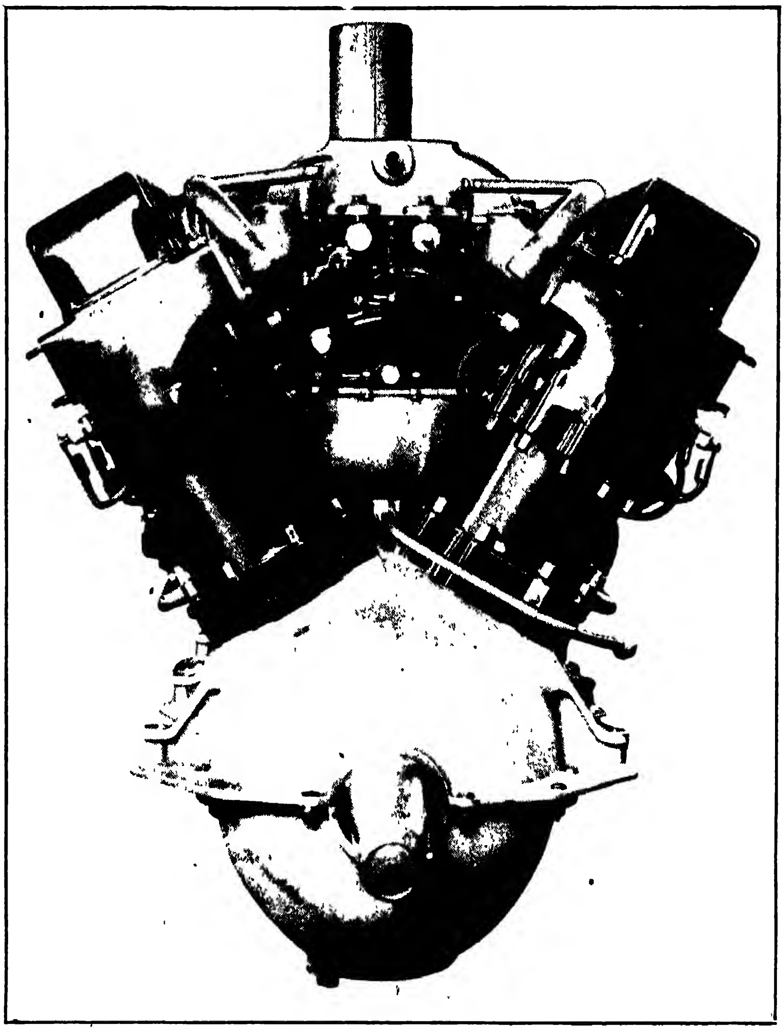


Fig. 182.—Direct Front View of Curtiss D 12 Water-Cooled Engine.

the crankcase cast in one block, the latter consisting of two K6 blocks mounted on one base in V form. Trouble was experienced in manufacture owing to the warping of the large castings so these engines were later redesigned to have the cylinder block and crankcase castings separate. Crankshafts were changed from four bearing to seven bearing and counterweights were eliminated. The remodelled K6 now known as the C6 is still built for commercial aviation service and delivers 160 horsepower and weighs 420 pounds.

Several hundred of these engines are now in service and are far more reliable than the Model OX-5, which has a good reputation in this respect. This six-cylinder engine weighs slightly less than the eight-cylinder OX-5 and delivers 50 more horsepower. It is not geared.

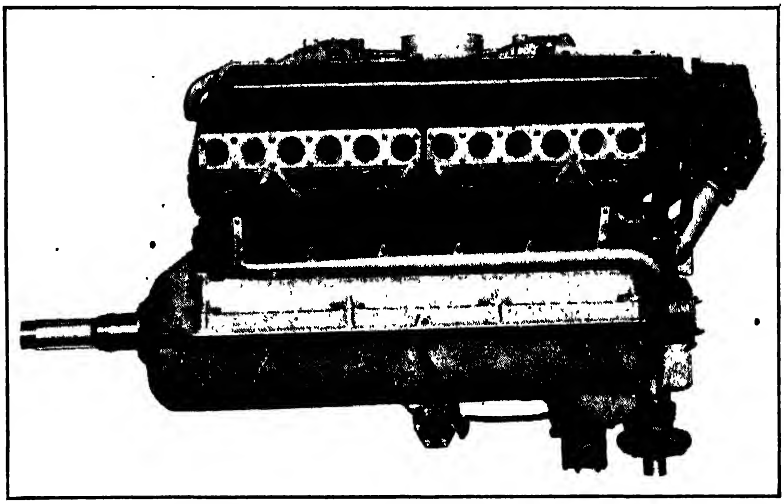


Fig. 183.—Side View of Curtiss V 1400 Aviation Engine which Delivers 510 Horsepower at 2100 Revolutions Per Minute and with a Dry Weight of 1.3 Pounds Per Horsepower.

The Curtiss D-12 engine which is shown at Figs. 181 and 182 was designed and built in 1921 and passed its official 50 hour test in the beginning of 1922. This engine was the result of all the experience gained from the previous models and weighed 690 pounds, which was 30 pounds less than the Model CD-12 engine. The bore and stroke were the same as in the latter, 4½ x 6 inch. The spark plugs were relocated, one between the exhaust valve and the other between the intake valves, directly opposite each other. The carburetion was also greatly improved over that of the preceding models. All the detailed parts and accessories that had previously given trouble were altered and improved. More than 350 of these engines have been built and have developed an average of 410 horsepower at 2,000 r.p.m. and 440 horsepower at 2,250 r.p.m., low compression.

The Air Service has pushed the development of this engine steadily by running 50 hour tests at various speeds at McCook Field. The engine has passed 50 hour tests at 2,250 and 2,450 r.p.m., and developed 455 horse-

power with low compression pistons in the test at the higher speed. Low compression is regarded as that compression ratio which will allow the engine to operate without detonation on domestic aviation gasoline containing no "dope." This high-speed 50 hour test was run without any forced stops or trouble of any kind. The engine is now rated at 435 horsepower at 2,300 r.p.m. Operation for more than 200 hours between overhauls is being obtained in service with this engine.

During the latter part of 1924 the Curtiss V-1400 engine, shown in Fig. 183 was designed and built. This model, which has a bore of 4⅞ inches and a stroke of 6¼ inches develops from 505 to 520 horsepower at 2,100 r.p.m., low compression, and more than 600 horsepower at the higher speed and with high compression pistons. It is lighter than the production D-12 engine, as it weighs only 685 pounds, dry, and fits in the same engine bearers. It is slightly narrower than the D-12 owing to the double camshafts being driven through three spur-gears instead of two, the bevel drive being attached to the third spur-gear, which is mounted below the two spur-gears on the ends of the camshafts. The sleeve construction is the same as in the D-12 except that the heads of the sleeves are open and are screwed into the aluminum heads against shoulders on the sleeves. The valves are seated on aluminum-bronze inserts in the aluminum head. The cooling water comes in contact with the steel sleeves, as in the D-12 engine, and the lower end of the sleeve is sealed with a composition gasket, as before. This cylinder construction is clearly shown at B, Fig. 166 in the discussion on water-cooled engine cylinder construction. Provision is made to use either battery or double-magneto ignition. The magneto is a Splitdorf double machine that operates with both armatures on one shaft and with two contact breakers, two coils and two condensers, all in the same machine. The distributors are mounted on the ends of the camshafts and are used with either the battery or the magneto ignition.

This V-1,400 engine, which weighs from 1.10 to 1.33 pounds per horsepower, depending on the power output, is more than 50 pounds lighter than its nearest competitor, either in this Country or abroad. The simplicity and sturdiness of the crankcase will be noted in the illustration. During its official fifty hour test, which was completed in 7 working days, the engine improved in power throughout the test. The short duration of the test alone indicates the remarkable reliability of the engine. The new type of cylinder construction improved the valve cooling, as is indicated by the fact that only 3 out of the 24 exhaust valves showed any leakage after the test. The average fuel-consumption during the test was 0.49 pounds per b.hp. hour. The average oil consumption was 0.018 pound per b.hp. hour, and the oil temperature difference between inlet and outlet was only from 12 to 14 degrees fahrenheit.

The small difference in oil temperature is most interesting, since a low oil temperature difference is highly desirable. With the production of very high horsepower in small units it is necessary to use an oil temperature regulating device in an airplane owing to the small crankcase area that is available for radiation. If the temperature difference is large, considerable heat must be dissipated, which presents a difficult problem. Air-cooling of oil has not been found satisfactory, since the oil in the cooler

congeals rapidly on the surfaces of the cooler and effectively insulates the remaining body of oil. In 1919 the Curtiss Company successfully adapted to its racing airplanes a method of oil-cooling by the use of the cooling-system water. A small-core radiator was inserted in the intake side of the water system. The oil was allowed to circulate through this core in the space usually provided for water in the conventional radiator, and the water was circulated inside of the cartridge tubes in the space ordinarily used for airflow. It was found that by this arrangement the oil temperature could be kept very close to the temperature of the water flowing into the engine, a very desirable arrangement.

CHARACTERISTICS V-1400

Length, overall	58-1/4"
Width, overall	26"
Height, overall	25-3/4"
Cylinders	12
Bore	4-7/8"
Stroke	6-1/4"
Compression ratio	5.5 : 1
Horsepower	510 BHP at 2100 RPM
Weight	660 pounds
Wt/H.P.	1.3 lbs./H.P.

Beardmore Six-Cylinder Engine.—While it is not possible in a book of this character to describe all known aviation engines, a recent British type is noteworthy in that it is an extremely large cylinder high-powered type. It is said to be one of the largest aircraft power plants yet constructed and is a six-cyclinder form as illustrated at Fig. 187. The cylinders are 8⅝ inch bore and 12 inch stroke with a compression ratio of 5.25 to 1. The dry engine weight is given at 2,150 pounds. The overall length of the unit is 80.3 inches with a maximum width of 35 inches, while the overall height is 60.37 inches, with a total height above the center-line of the crankshaft of 45.25 inches, and a maximum depth to the lowest point below the crankshaft center of 15.12 inches. The engine is water-cooled and a circulating pump is fitted. The ignition system is in duplicate, and two magnetos are employed. As illustrated, the engine is designed for a left-hand tractor-type propeller running at a normal speed of from 1,220 to 1,350 r.p.m. according to the power it is desired to develop.

In getting out the new design the object in view was to develop as high a power as possible in a few cylinders. It was also sought to reduce the number of engine parts while retaining the maximum accessibility. An outstanding feature of the engine is its compact and clean outline, which enables it to be installed in a very narrow fuselage, thereby reducing considerably the amount of head resistance which would be offered by an engine either of the radial or the V-type. The crankcase, which is made in aluminum, forms the main engine body. It incloses the crankshaft and its bearings, which are carried on transverse girders, while the camshaft is accommodated in the top part of the casing. At the level of the crankshaft, the body is swelled out to give great lateral strength to the crankcase about the crankshaft, and permit of direct connection to the engine bearers, while

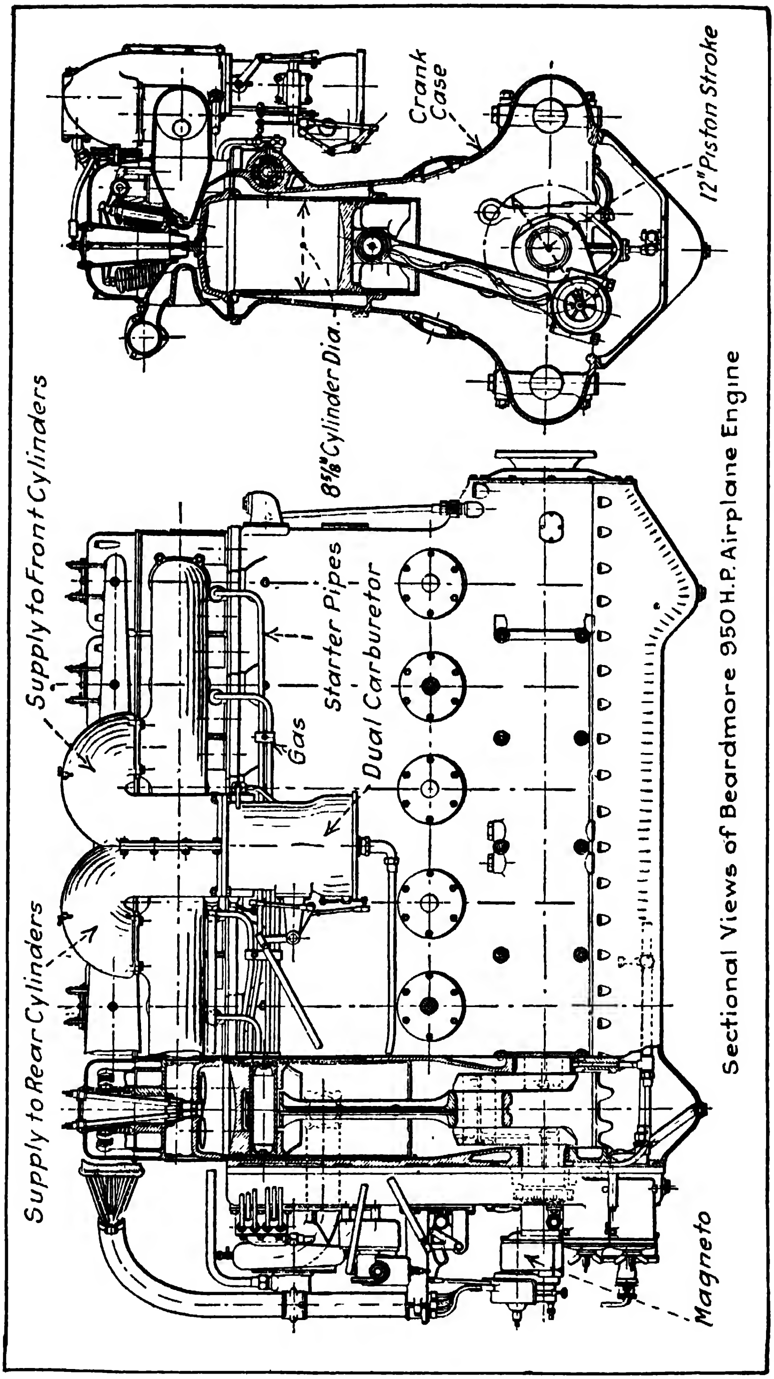


Fig. 184.—Sectional Views of Beardmore Six Cylinder Aircraft Engine, a Six Cylinder Form Rated at 950 Horsepower.

underneath there is a removable oil sump. Access to the working parts is given by inspection doors, which are fitted to each cylinder, one on either side of the crankcase. Cylinder liners of thin steel are inserted into the upper part of the casing, and are supported both at the top face and by a lower ring, which incloses the cooling water space.

It will be seen that the cylinder head and valve gear form a separate unit, which is readily detachable. For each cylinder there are two exhaust and two induction valves which are operated through rocker levers by short push rods. As shown in the left-hand cylinder section, twin spark plugs are fitted in the crown of the cylinder head and are well cooled. The same illustration shows the end gearcase inclosing the gear drive from the crankshaft. The camshaft, it will be seen, is driven by a series of intermediate gears, which in turn are usually employed to drive various accessories mounted on the end case. This casing, with its attachments, is so designed that it can be removed from the engine in a few minutes while each accessory can, when required, be quickly detached. The various auxiliary fittings referred to, include, besides the two magnetos, the lubricating oil pressure and suction pumps, the circulating water and fuel pumps, as well as a gas distributor, and gun gear, when the engine is designed for use in a military machine. At the bottom of the gearcase there are duplex lubricating oil filters on both the pressure and suction sides of the oil system. The filters are provided with change-over valves, so that either can be cleaned while the engine is running.

Brief reference may be made to the lubricating system. Oil is delivered under pressure to the main bearings, and passes by means of drilled passages to the big ends, after which it is taken up to the piston pins through tubular connections, which are strapped to the webs of the steel connecting rods. A hollow piston pin, with closed ends, is used. The piston is made of forged and machined aluminum, and is fitted with three piston rings and one scraper ring. All of the wheels have ground teeth, and ample lubrication is provided by the oil, which returns from the pressure-fed camshaft bearings.

The engine described was fitted with a 97 mm. Zenith twin carburetor, which works together with an induction system, that has been evolved as the result of considerable experimental work. The test results given below apply to the engine fitted with this carburetor, but a superior performance which approximates more closely to the standard type of engine is given when a 120 mm. carburetor is fitted.

TEST RESULTS

Speed, load and power			Fuel-consumption	
R.P.M.	Pounds loads	B.H.P.	Average fuel used per hr., gal.	Pounds per B.H.P. hour.
1220	710	722	44.22	0.465
1220	795	808	51	0.48
1350	843	949	63.75	0.512

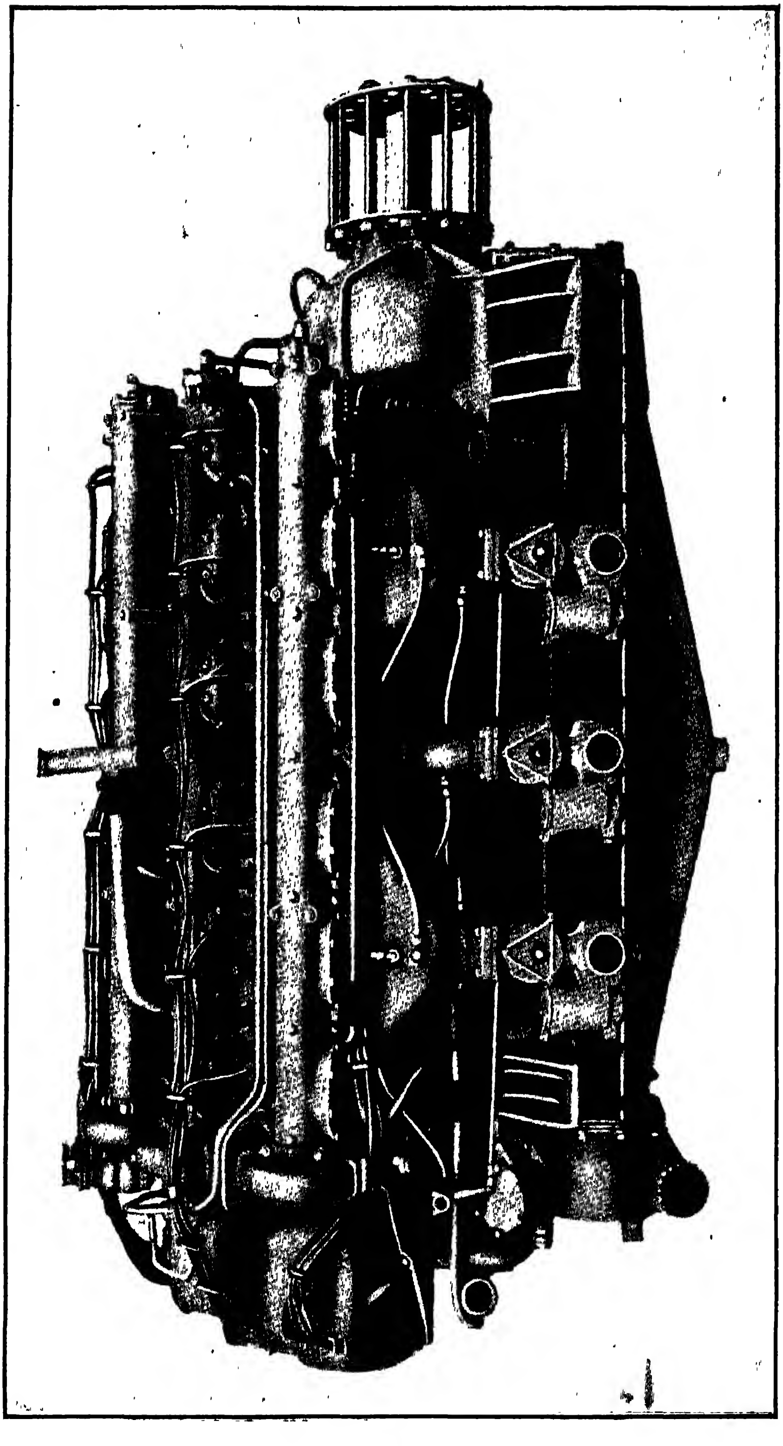


Fig. 184A.—Side View of Eighteen Cylinder Water-Cooled Sunbeam-Coatalen Aircraft Engine Rated at 475 Horsepower.

Many Materials Used in Aviation Engines.—Mr. Arthur Nutt, M. S. A. E. of the Curtiss Aeroplane and Motor Company, Inc. engineering department commented on materials used and how the intelligent application of light and strong materials has greatly increased airplane engine performance and reduced the weight in a paper read before the Buffalo Section of the S. A. E. He said in part:

It will be seen from the foregoing models and the discussion of their construction that the problem in designing aircraft engines is to obtain the best relation of (*a*) weight, (*b*) frontal area, (*c*) cost, (*d*) bulk, (*e*) high performance, and (*f*) reliability. If the weight and bulk requirements were unnecessary the problem would be much simpler. The aeronautic engineer is not held down on cost to anywhere near the same extent as the automobile engineer when designing automobile engines; however, that he also has competitors in his own field must be borne in mind and, while the aircraft engine is strictly limited in weight, it must operate at very high duty and with extreme reliability.

All of these problems are involved with the proper arrangement of parts, which can be secured only as a result of experience, and with the proper selection of materials. More than 40 different kinds of material are used in the modern aircraft engine. The most interesting materials are the light and unusual alloys. Magnesium probably is one of the more interesting of these to engineers who are not connected with the aircraft industry. This alloy is 40 per cent lighter than aluminum, has an average tensile strength of 20,000 pounds per square inch and an elongation of 4 per cent. It is comparable in strength and elongation with the best non-heat-treated commercial aluminum crankcase alloys. The lighter alloys of magnesium, alloyed with about 5 per cent of aluminum, are much less subject to corrosion than the original alloys that were produced. This alloy has been cast in almost every form that is used in an aircraft engine; however, the present cost of production prohibits its use in quantity. It is hoped that in the future sufficient quantities will be available so that the material can be used with success in our later models and in production engines. With this material available economically and with higher engine speed, remarkable performances may be expected.

Aluminum-bronze is another material that has come into extensive use in aircraft engines. This makes a very remarkable valve insert metal, as its coefficient of expansion is about the same as that of aluminum. The valve seat, after a few hours of engine running, presents a mottled appearance almost as if the metal were pitting. We find, however, that this is not the case and to recut the seats because of this appearance is not wise. The valves will continue to function for hundreds of hours without trouble with this construction if the proper cooling is provided around the valve insert. The material can be heat-treated to give about 200 Brinell hardness for this work. In alloys with iron and steel, the Brinell hardness can be raised to more than 300 by heat-treating.

Duralumin is an alloy with which nearly everybody in the automotive industry today is familiar. It is used extensively in modern engines, in both the cast and forged forms. It is particularly advantageous in the forged form owing to the small amount of work that is necessary on the

forgings after they are received. The finish of the forgings is perfectly satisfactory and it is necessary only to remove the flash before putting the forgings into the machine shop. We have found that the cast high-tensile aluminum alloy is unusually satisfactory for cylinder heads. The average tensile strength is more than 30,000 pounds per square inch and elongation about 6 per cent. It is extremely non-porous and very uniform in texture, and it machines very satisfactorily. The cylinder heads and water jackets of our water-cooled engines and in the crankcases of the air-cooled engines are the places where this alloy is used. It is approximately 10 per cent lighter and nearly 100 per cent stronger than the usual crankcase aluminum alloys.

Y-alloy is an alloy of aluminum with copper, nickel and magnesium. It is used for pistons in all our engines and in the cylinder heads of our air-cooled engines. This material is a light aluminum alloy owing to its low

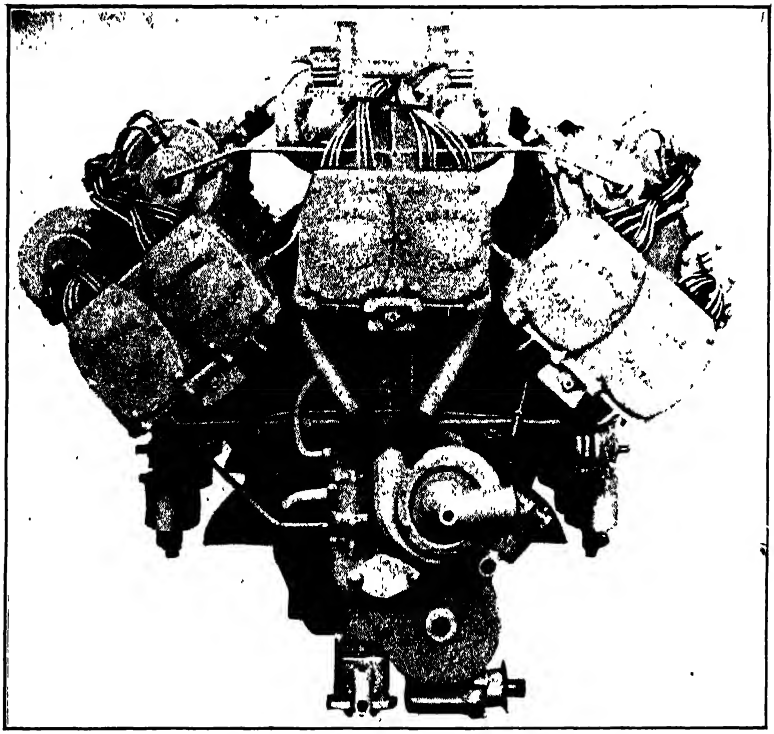


Fig. 184B.—Sunbeam Eighteen Cylinder Aircraft Motor Viewed from the Pump and Magneto End.

copper content, and is a wonderful bearing material. It seems to be as strong as the high-tensile aluminum alloys similar to duralumin, in the heat-treated condition, but has a marked advantage over them in the property of great strength at high temperature. Y-alloy apparently has not been used to a great extent in the automotive field except in pistons, because of its high cost due to the heat-treating operation. High-silicon aluminum alloys are used for sections varying from 3/32 to ⅛ inch in thickness.

Sunbeam Aviation Engines.—These very successful engines have been developed by Louis Coatalen. At the opening of the war the largest sized Coatalen motor was 225 horsepower and was of the L-head type having a single camshaft for operating valves and was an evolution from the twelve-cylinder racing car which the Sunbeam Company had previously built. Since 1914 the Sunbeam Company have produced engines of six, eight, twleve and eighteen cylinders from 150 to 500 horsepower with both iron and aluminum cylinders. For some time past all the motors have had overhead camshafts with a separate shaft for operating the intake and exhaust valves. Camshafts are connected through to the crankshaft by means of a train of spur gears, all of which are mounted on two double row ball bearings. In the twin six, 350 horsepower engine, operating at 2,100 r.p.m., requires about 4 horsepower to operate the camshafts. This motor gives 362 horsepower at 2,100 revolutions and has a fuel-consumption of 51/100 of a pint per brake horsepower hour. The cylinders are 110 by 160 millimeters. The same design has been expanded into an eighteen-cylinder which gives 525 horsepower at 2,100 turns. There has also been developed

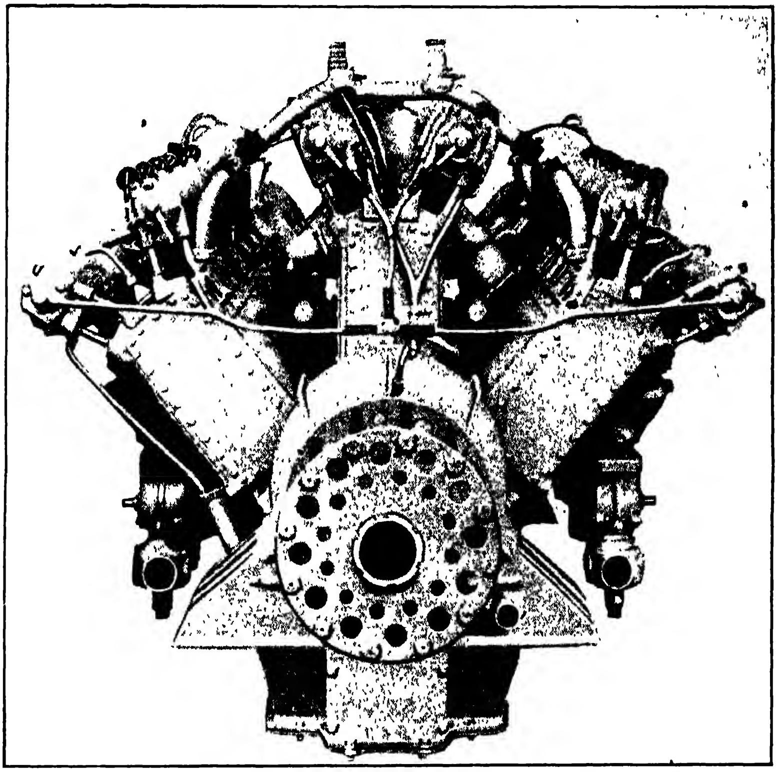


Fig. 184C.—Propeller End of the Sunbeam Eighteen Cylinder 475 Horsepower W Type Aircraft Engine.

a very successful eight-cylinder motor rated at 220 horsepower which has a bore and stroke of 120 by 130 millimeters, weight 450 pounds. This motor is an aluminum block construction with steel sleeves inserted. Three

valves are operated, one for the inlet and two for the exhaust. One camshaft operates the three valves.

The modern Sunbeam engines operate with a mean-effective pressure of 135 pounds with a compression ratio of 6 to 1 sea level. The connecting rods are of the articulated type as in the Renault motor and are very short. The weight of these motors turns out at 2.6 pounds per brake horsepower, and they are able to go through a 100 hour test without any trouble of any kind. The lubricating system comprises a dry base and oil pump for drawing the oil off from the base, whence it is delivered to the filter and cooling system. It then is pumped by a separate high pressure gear pump through the entire motor. In these larger European motors, castor oil is used largely for lubrication. It is said that without the use of castor oil it is impossible to hold full power for five hours. Coatalen favors aluminum cylinders rather than cast iron. The broad arrow type wherein three rows, each of six cylinders, are set on a common crankcase is shown at Figs. 184, A, B, and C. In this water-cooled series the gasoline and oil consumption are notably low, as is the weight per horsepower.

In the eighteen-cylinder overhead valve Sunbeam-Coatalen aircraft engine of 475 brake horsepower, there are no fewer than half a dozen magnetos. Each magneto is inclosed. Two sparks are furnished to each cylinder from independent magnetos. On this engine there are also no fewer than six carburetors. Shortness of crankshaft, and therefore of engine length, and absence of vibration are achieved by the linking of the connecting rods. Those concerned with three cylinders in the broad arrow formation work on one crankpin, the outer rods being linked to the central master one. In consequence of this arrangement, the piston travel in the case of the central row of cylinders is 160 mm., while the stroke of the pistons of the cylinders set on either side is in each case 168 mm. Inasmuch as each set of six cylinders is completely balanced in itself, this difference in stroke does not affect the balance of the engine as a whole. The duplicate ignition scheme also applies to the twelve-cylinder 350 brake horsepower Sunbeam-Coatalen overhead valve aircraft engine type. It is distinguishable, incidentally, by the passage formed through the center of each induction pipe for the sparking plug in the center cylinder of each block of three. In this, as in the eighteen-cylinder and the six-cylinder types, there are two camshafts for each set of cylinders. These camshafts are lubricated by low pressure and are operated through a train of inclosed spur wheels at the magneto end of the machine. The six-cylinder, 170 brake horsepower vertical type employs the same general principles, including the detail that each carburetor serves gas to a group of three cylinders only. It will be observed that this engine presents notably little head resistance, being suitable for multi-engined aircraft.

Farman Aviation Motor, 600-Hp. 18-Cylinder W-Type.—In this motor the cylinders are 130 mm. (6.1 inch) bore by 180 mm. (7.1 inch) stroke, located in three rows 40 degrees apart. This angle of 40 degrees was determined with a view to having a steady torque, the motor giving 18 impulses in each two revolutions or 720 degrees, which gives one power stroke for each 40 degrees.

The crankshaft has six throws. The use of a W-type motor was con-

sidered to be of advantage as it reduces the size of the crankcase. The increase in the number of cylinders leading to a reduction of the unit cylinder volume permits of a higher compression without fear of self-ignition owing to heating of the center of the piston. The weight of the motor with its full equipment of ignition carburation pumps, etc., is only about 780 kg. (1,716 pounds) for an effective horsepower of about 800 at 2,200 r.p.m. (The nominal rating of the motor is 600 horsepower at 1,750 r.p.m.)

The motor drives the propeller through a reducing gear weighing 45 kg. (99 pounds). In addition to this there is a 1,200-watt generator with a wireless-telegraph alternator weighing 34 kg. (86 pounds), and the total weight of the motor with all accessories including propeller hub is 920 kg. (2,025 pounds). The cylinders are grouped in pairs and the compression ratio is six to one.

The cylinders are made from forgings and welded together in pairs. Each pair has a common water jacket made of sheet steel and welded over the group. There are four valves per cylinder, these valves being made of high-nickel steel. Each valve has two concentric springs wound in opposite directions and each cylinder carries three spark plug bosses, two side by side and the third 180 degrees therefrom; this third boss is intended for the insertion of starting devices, be they explosive cartridges or compressed air plugs. In connection with lubrication it is of interest to note that the oil filters are so arranged that they can be inspected while the engine is running. A safety valve is provided on the oil circulation pump to open when the oil pressure becomes excessive. The purpose of this is to prevent the breaking of the oil radiator at starting in cold weather when the oil is very viscous. Four Zenith carburetors are provided, two with single outlets and two double ones, each outlet feeding three cylinders. The carburetors are fed by two A M fuel pumps connected in parallel, each pump, being, however, of sufficient capacity to supply fuel to all the four carburetors. There is a device for setting these pumps in operation automatically as soon as the electrical starter begins running, in addition to which the pumps may be also started by hand. As it would be impracticable to start a motor of this size by hand, an electric starter has been provided.

QUESTIONS FOR REVIEW

1. Describe main features of Liberty engine.
2. Outline the difference between the wet and dry sleeve methods of building water-cooled cylinders.
3. How are exhaust valves cooled in Packard water-cooled engines?
4. Describe multiple cluster valve springs and give advantages.
5. What is a "dry sump" lubrication system?
6. What is the difference between Curtiss and Packard cylinder construction?
7. What materials are used in water-cooled aircraft engine construction?
8. Why is geared propeller drive used on some engines?
9. Where is the camshaft located and how is it driven on most aircraft engines? How are the valves actuated?
10. What is the dry weight and horsepower of the Liberty engine? What is the fuel-consumption?

CHAPTER X

AVIATION ENGINE AUXILIARIES

Wright Oil Temperature Control System—Aircraft Engine Starting Methods—Aeromarine Inertia Starter—The Wright Starter—Eclipse Aviation Engine Starters—Hand and Electric Inertia Starters, Series 7—Eclipse Electric Starter—The Bristol Gas Starter—Air Starting System—Fuel Tanks and Supply Systems—Fuel Displaced by Air Pressure—Duralumin Fuel Tanks—Aircraft Carburetors—Airplane Engine Superchargers—Turbo Superchargers—Root's Blower.

Wright Oil Temperature Control System.—Failures of the lubricating system have caused the loss of hundreds of valuable aviation engines, severe damage to the airplanes in which they were installed and have often placed the airplane personnel in great danger. These failures have frequently resulted from a lack of proper control of the oil temperature, so that the oil either became too cold to flow into the engine fast enough to give sufficient oil pressure, or else became so hot as to lose its effectiveness as a lubricant. Trouble due to cold oil has generally occurred in starting the engine in cold weather, and the usual means of overcoming it has been to drain the oil from the tank, heat it over a stove, and pour it back, an operation which is always inconvenient, and often impracticable. To keep the oil from becoming too hot, air-cooled oil radiators or water pipes in the oil tank have been used, but these have not been entirely satisfactory. After a long series of experiments, both in the dynamometer room and on airplanes in the field, our engineering department has developed an oil temperature regulator, which heats the oil rapidly in starting and then holds its temperature at the proper point for good lubrication. Tests have demonstrated the effectivenes of this system both in hot and cold weather.

Alhough designed primarily for the control of oil temperature, this system has proved successful in the control of water temperature. In actual service it has replaced radiator shutter control with a resultant improvement in airplane performance, due to the elimination of the head resistance of the radiator shutters. An instance of this improved performance was reported during the trials of the Navy SC-1 Torpedo Scouting planes. These planes are fitted with particularly large radiators and it was found that with the shutters closed for cold weather operation, the closed shutters gave considerable drag. This was overcome by leaving the shutters open, using an anti-freezing mixture and controlling the water temperature by the manually operated by-pass which is a part of the Wright Oil Temperature Control System. With the shutters wide open, the pilot was able to control the temperature of the oil and water at will and the ceiling of the airplane was greatly improved. Acting on the evidence of these trials the radiator shutters on these planes were removed; since the operation of the by-pass valve is just as simple as the operation of the radiator shutters and has the advantage of giving better performance. A summary of the advantages follows:

(1) Sufficient oil pressure in starting to enable the engine to be idled safely, even in cold weather with cold oil.
(2) Full oil pressure in five to eight minutes, starting with cold oil.
(3) Reduction in time required to warm engine.
(4) Maintenance of oil temperature at proper point both in hot and cold weather.
(5) Elimination of necessity of draining oil tank overnight in cold weather.
(6) Ease of installation.
(7) Flexibility in design, allowing its use in airplanes already built.
(8) Simplicity in operation.
(9) Economy in oil.
(10) Protection of engine, airplane and personnel from a frequent and dangerous source of trouble.
(11) Correct engineering principles for maximum heat transfer per square foot of cooling surface.
(12) Eliminates necessity for pre-heating oil.
(13) Facilitates heating water in cold weather.

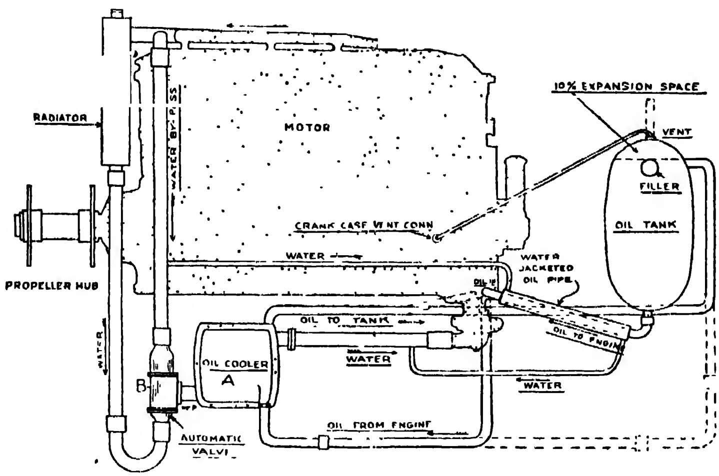


Fig. 185.—Typical Installation of Wright Oil Temperature Control System, Showing Heat Transfer Unit A and Automatic Valve B.

The Wright Oil Temperature Control System consists of a heat transfer unit or oil cooler shown at Fig. 185 A (marked "A" in the illustration Fig. 185), a three-way value (marked "B'), operated either by hand or by a thermostat, and the necessary water and oil piping. The heat transfer unit consists of a nest of thin copper tubes, with a shell and headers so arranged that the oil flows through the tubes, and the engine cooling water flows through the space between them. In this way the more viscous liquid has the path of lower resistance, and obstruction of oilflow is avoided. The headers are of cast aluminum alloy and are readily removable, and the whole

unit is designed with ample strength to prevent distortion or leaks under service pressures. All the oil and water pass through the heat transfer unit at all times. The three-way valve controls a by-pass around the main water radiator, so that no water passes through the radiator until the water temperature has risen to its normal operating value. In this way the water temperature rises rapidly in starting, and the oil is quickly warmed. When normal operating conditions have been reached, the water keeps the oil cool. We recommend a water jacket on the oil line from the tank

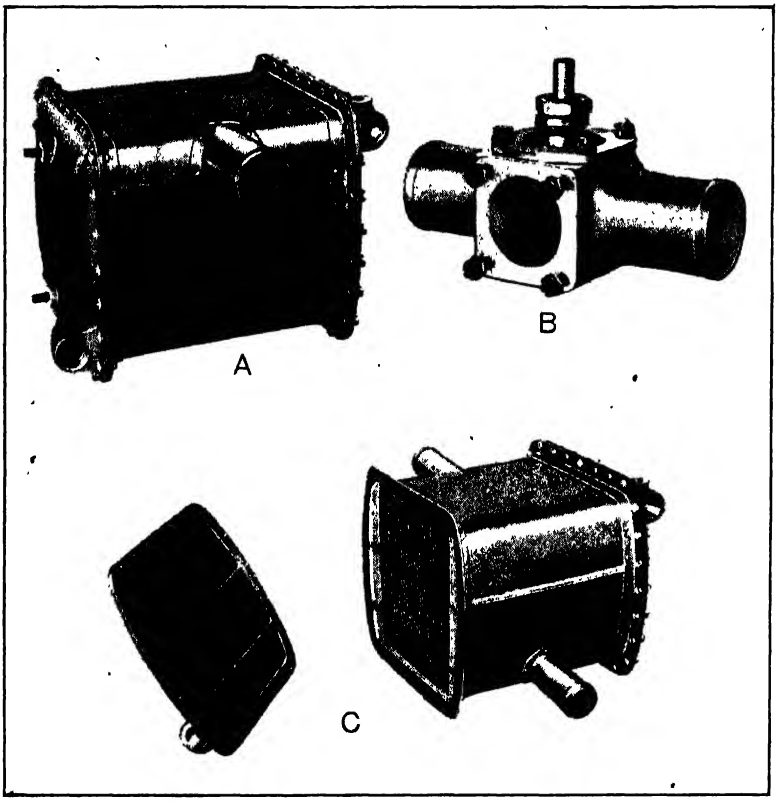


Fig. 186.—Parts of Wright Oil Temperature Control System. A—Heat Transfer Unit or Oil Cooler. B—Three Way Valve. C—Heat Transfer Unit with End Plate Removed.

to the engine, so that flow in this line may not be obstructed by cold oil. The use of a baffle in the tank to direct the incoming oil toward the outlet is also desirable, as it enables warm oil to reach the engine before the whole volume of oil in the tank is warm.

The heat transfer unit is usually installed on the discharge side of the scavenging oil pump of the engine, that is, on the "pressure side" of the lubricating system. In this installation each unit may be placed wherever space is available for it. In a new design, however, it is sometimes possible to combine the oil tank and the heat transfer unit with the heat

transfer unit on the bottom of the tank. The oil then flows from the tank directly into the heat transfer unit, and from there to the engine. The heat transfer unit is thus in the intake line of the pressure oil pump of the engine, that is, on the "suction side" of the system. This latter arrangement materially reduces the piping, but of course requires care in the design to provide the space necessary for the combined tank and heat transfer unit. In either type of installation, the water connections can be placed in almost

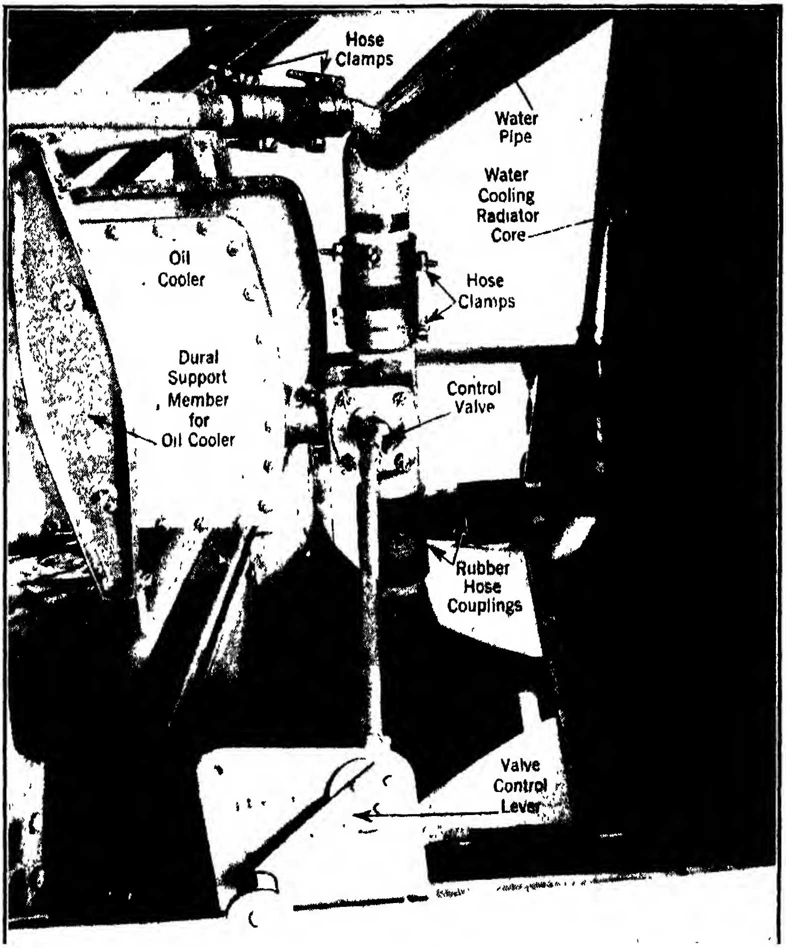


Fig. 187.—Wright Oil Cooler and Manual Control Valve as Installed in Airplane.

any position desired on the unit, and the headers can be turned so as to provide several different positions for the oil connections. The installation of the heat transfer unit with manual control value is shown at Fig. 187.

Two sizes of heat transfer unit are manufactured, one for engines from 400 to 650 hp. and the other for engines of 650 hp. to 750 hp. The dimensions and weights of these are as follows:

400 H.P. TO 650 H.P. UNIT	650-750 H.P. UNIT
Overall dimensions—13" x 12⅞" x 8⅞".	Overall dimensions—13⅜" x 13" x 12¼".
Size of oil connections—¾" pipe tap.	Size of oil connections—¾" pipe tap.
Size of water connections—2" outside diam.	Size of water connections—2" outside diam.
Weight, empty—25 pounds.	Weight, empty—31 pounds.
Weight of contained water—10½ pounds.	Weight of contained water—14½ pounds.
Weight of contained oil—12½ pounds.	Weight of contained oil—13 pounds.
Cooling surface—32 sq. ft.	Cooling surface—50 sq. ft.
5-pass, giving equivalent tube length 45".	5-pass, giving equivalent tube length 45".

(a) Acting as a cooler, the 400 to 650 hp. regulator is guaranteed to cool 5.5 gallons of oil per minute through 20 degrees fahrenheit when supplied with 70 gallons of water per minute and when the temperature of the oil entering the cooler is not less than 35 degrees fahrenheit above the temperature of the water entering the cooler.

(b) Acting as a heater, the 400 to 650 hp. regulator is guaranteed to heat 5.5 gallons of oil per minute through 20 degrees fahrenheit when supplied with 70 gallons of water per minute, provided the temperature of the oil entering the heater is at least 40 degrees fahrenheit lower than the temperature of the water entering the heater.

EXAMPLE AS COOLER

Actual Tests

Wright T-3 Engine, 1,947 cu. in. displacement.	Outlet water temperature, 180° F.	Average oil pressure drop through oil radiator 0.3 lbs. per sq. in.
Average at 1,800 r. p. m., full throttle, 575 H.P.	Inlet water temperature, 150° F.	Average oil pressure in radiator:
Waterflow, 70 gals. per min.	Inlet oil temperature, 180°	Inlet 3.3 lbs. per sq. in.
Oilflow, 5.5 gals. per min.	Outlet oil temperature, 160° F.	Outlet 3.0 lbs. per sq. in.

The following data was obtained during three ground tests of planes equipped with the 400-650 hp. oil temperature regulator:

EXAMPLES AS HEATER

Actual Tests on Three Different Planes

Date	Air Temp.	Oil Temp. At Start	Time Required to Obtain Initial Oil Pressure	Time Required to Obtain Full Oil Pressure	Oil Temp. at Instant Full Oil Pressure was Rep't'd
Jan. 4, 1924	45° F.	58° F.	Less than 1 min.	6 min.	72° F.
Jan. 24, 1924	40° F.	45° F.	Less than 1 min.	8 min.	102° F.
Mar. 10, 1924	44° F.	60° F.	Instantaneously	5 min.	87° F.

Aircraft Engine Starting Methods.—The method employed in starting airplane engines by "swinging the stick," as shown at Fig. 188 worked satisfactorily with small engines, but as engine sizes increased, the problem became one that needed considerable study for its solution. The need for a mechanical starting arrangement became particularly keen when the Liberty engine was first used and it required two or three men to start

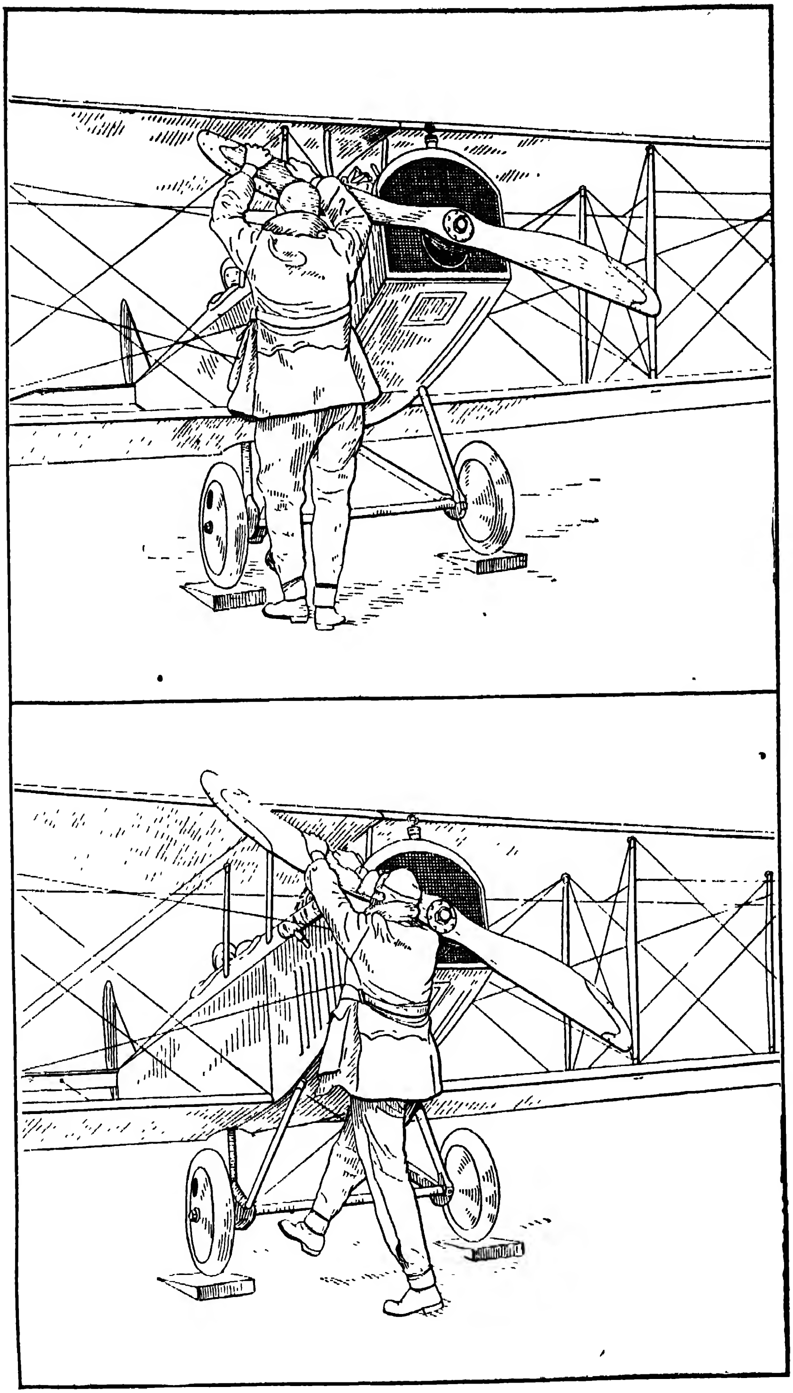


Fig. 188.—Illustrations Depicting Wrong and Right Methods of "Swinging the Stick" to Start Airplane Engine. At Top—Poor Position to Get Full Throw and Get out of the Way. Below—Correct Position to Get Quick Turn over of Crankshaft and be Able to Spring Away from the Revolving Propeller as Soon as Engine Starts.

that engine by turning the propeller. After the propeller had been turned over a number of times and engine primed with the switch off, contact was established and one man turned the propeller and his efforts were aided by one or two others who clasped hands and pulled him away when the engine started. The location of the engines in twin engine bombing planes and seaplanes were sometimes such that "swinging the stick" was not practical because the engines were out of reach. When engines were used in dirigible balloons and carried in power cars mechanical starting means were imperative because they could not be started from the ground. Various types of engine starters have been devised. Some utilize the energy

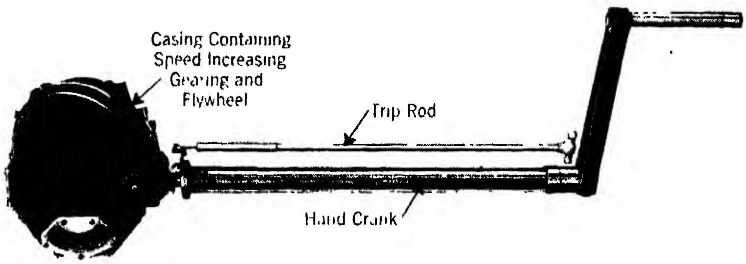


Fig. 189.—Aeromarine Inertia Engine Starter.

stored in a rapidly revolving flywheel and are known as inertia starters. The flywheel momentum may be obtained by spinning it by a hand crank or electric motor. Then there is a hand cranking and electric spark type. Electric starting motors similar to those employed in automobiles have been used. Air starting system have been used on airship engines and gas starters on large aircraft engines.

The Aeromarine Starter.—This is a hand starter in which the cranking energy of the operator is not applied directly to turning over the engine crankshaft, but instead is used to start a flywheel rotating and bring it to a high speed. When the operator has stored sufficient energy in this flywheel, he stands away, free of all contact with engine or starting mechanism, and pulls a light control rod which connects the starting mechanism to the engine. This diverts the energy stored in the flywheel through a train of gears into turning over the engine crankshaft. A fraction of a minute is sufficient to store the required amount of energy for starting a 600 horsepower engine, the length of time depending entirely upon the zeal of the operator.

The flywheel starter excels other starting devices for aircraft engines, whether power operated or hand operated, in its initial cranking speed, which may be well over 100 r.p.m. While the starter only turns the crankshaft a few revolutions, this initial kick at high speed results in good distribution and compression, and makes it possible to easily start large engines directly on the magnetos even when cold and with the spark fully advanced.

Another advantage which is greatly appreciated by the mechanics who

have to start these engines, is that the operator can work with a smooth easy pull on the handle and take his time at the job of speeding up the starter flywheel. He is therefore not subjected to the severe strain required to turn a big engine over the compression peaks when the ordinary hand starter is used. Furthermore, when the actual start is made, he is entirely clear of the starting mechanism and free from the possibility of injury from backfires, etc. As a further caution against any possibility of injury to the operator, a ratchet is provided on the hand crank shaft which is automatically disengaged by the same mechanism that connects the starter to the engine so that in case the operator should keep his hand on the hand crank while pulling the control rod he will still be unharmed should a backfire occur.

In order to prevent any possibility of damage to the engine parts at the instant of engagement of the starter jaw with the companion jaw on the engine crankshaft, the device is provided with a specially designed overload releasing clutch which may be set to allow the development of a definite maximum torque at the crankshaft, and is capable of holding this setting indefinitely within very close limits. This clutch acts to absorb the shocks from backfires as well as during the initial engagement of the starter jaws.

The inertia starter will give the engine crankshaft from three to eight rapid turns, depending upon the stiffness of the engine, at a speed many times that of the electric or hand starters heretofore used. As many as twelve starts of a Liberty engine in normal running condition have been made with a single cranking of the flywheel. Its weight is about the same as the lightest electric starter without the storage battery, and it therefore represents a substantial saving in weight as against the electrical equipment as a whole.

When the suggestion of starting an aircraft engine by means of a flywheel was first brought forward, it created considerable amusement among those whose primary object in design is directed toward obtaining the lowest possible weight-power ratio. The term "flywheel" is always associated with something very heavy. This however, in the case of stored energy, depends entirely upon the speed at which it is possible to drive the flywheel, and as the stored energy increases as the square of the speed, it will be seen that by using a large gear reduction, a very small flywheel may be made to do a large amount of work. For instance, the flywheel in the Aeromarine Inertia Starter weighs only five pounds and is only five inches in diameter, but on account of its high rotative speed, it has a very large capacity for storing energy. It may be easier to imagine just how great this energy capacity is if it is considered that an equivalent flywheel without any gear reduction and two feet in diameter instead of five inches would have to weight over 5,000 pounds—or more than 1,000 times the weight of the Inertia Starter Flywheel.

The gear ratio used is 162 to 1 between the hand crank and the flywheel, so that a hand crank speed of 100 r.p.m. turns the flywheel over at more than 16,000 revolutions per minute. The gear reduction between the flywheel and the engine crankshaft is slightly less (133) so that the starter jaw turns about 25 per cent faster than the hand crank.

This large gear ratio is obtained in the type of starter illustrated with two spur gear reductions, the second one involving the use of the Aeromarine standard five tooth pinion. All gears are mounted on ball bearings and are of the Maag tooth outline, which makes for great strength and high efficiency. The meshing mechanism for connecting the starter to the engine is provided with a toggle spring which provides a very quick engagement and thus insures that the jaw teeth engage to the full depth and do not catch on the edges. The starter is mounted in an oil tight cast aluminum casing and all external steel parts are finished in dull nickel.

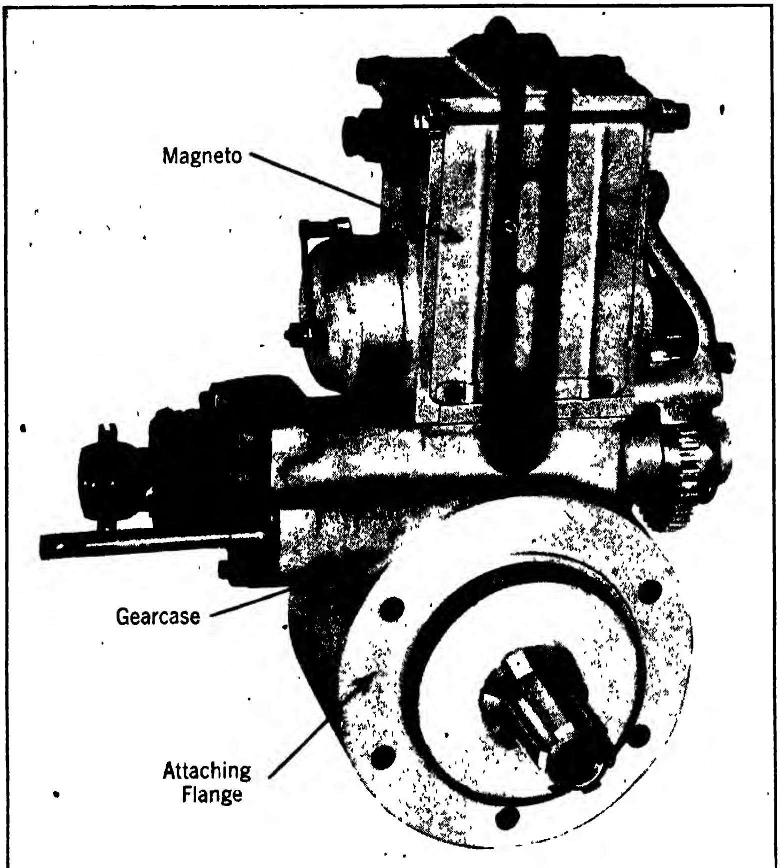


Fig. 190.—Wright Hand Turning Gear and Starting Magneto.

The Wright Starter.—The Wright Hand Turning Gear is the successful result of several years of work in the development of a device by which an aviation engine may be started readily by hand, without danger of injury to the operator or damage to the engine or starter. The gear is simple, compact, and reasonable in weight, and may be used on engines of widely different sizes without any change other than a simple adjustment. It is supplied in two gear ratios, 6 to 1 or 15 to 1, as specified by the customer.

In the illustration at Fig. 190, which shows the side of the starter toward the engine, most of the external parts of the gear are visible. The splined shaft fits into the rear end of the engine crankshaft and the five holes receive five studs by which the gear is bolted to the rear end of the crankcase. The bolting flange and spline are designed to fit the standard army and navy starter mounting as used on Liberty, Wright, Curtiss and other engines. The starter shaft carries a bronze worm wheel, which engages a worm driven by the handcrank. The starting magneto, which is an integral part of the device, is also driven by the starting crank, through gears.

In starting, the worm is brought into contact with the worm wheel by pushing on the small rod beside the starting crankshaft. Turning the crank then brings the worm into full engagement, and further turning rotates the engine crankshaft. When the engine fires, the worm is thrown out of engagement, but as it slides endwise on its shaft no end motion is transmitted to the starting crank. The disengagement of the worm, however, does not throw the starting magneto out of gear, so that it may be kept in operation by turning the hand crank until the engine has picked up enough speed to fire regularly on the running magnetos. The starting magneto furnishes high tension current which is distributed to the spark plugs through one of the main magnetos. It is designed to operate in connection with a "trailing brush" on the running magneto, which gives a greatly retarded spark, thus reducing to a minimum the probability of the engine "kicking back." However, should a "back-kick" occur while the engine is being cranked, the engine and starter are positively protected against damage by a multiple disc friction clutch, interposed between the worm wheel and the splined shaft, loaded by four carefully equalized springs. Thus a "kick back" results merely in slipping this clutch. An external ratchet on the starting crank shaft positively prevents the crank from turning backwards. The only adjustment required is for spring tension of the friction clutch. This adjustment is made at the factory to suit the particular engine with which the turning gear is to be used, and ordinarily does not require further adjustment in service. Thus the gear requires no attention or adjustment after installation on the engine.

The addition of the turning gear increases the length of the engine by 4⅛ inches, and a space of 4⅞ inches is necessary to remove it without disturbing the engine. The weight of the gear, including the magneto but not the hand crank, is 25 pounds. The starting magneto is attached to the gear by a special strap which permits its removal without the use of wrenches, a feature of great advantage in working in the space between the engine and the fire-wall. The crank may be attached to either end of the worm shaft, and the gear as a whole may be mounted in several different angular positions. With an adapter plate between the gear and the engine, any desired angle between the starting crank and the horizontal may be obtained. The starting crank is made up with a long shank and is supplied with the end fittings not attached, so that it may be cut to the length best suited to the airplane in which it is used.

The gear ratio between the hand crank and engine crankshaft is such that under ordinary conditions one man can turn the engine, unless the

location of the crank with respect to other parts of the airplane is such as to prevent him from exerting his strength effectively. To meet unfavorable conditions, the grip on the crank has been made long enough to allow for cranking by two men. The hand crank is usually pinned permanently to the starter shaft, so that it may be carried in position, but if desired, the end of the crank may be fitted with a slot to allow it to be removed. Ball bearings on the spline shaft and on the worm shaft take the thrusts of the worm and gear. All parts are thoroughly lubricated by pressure feed from the engine oiling system.

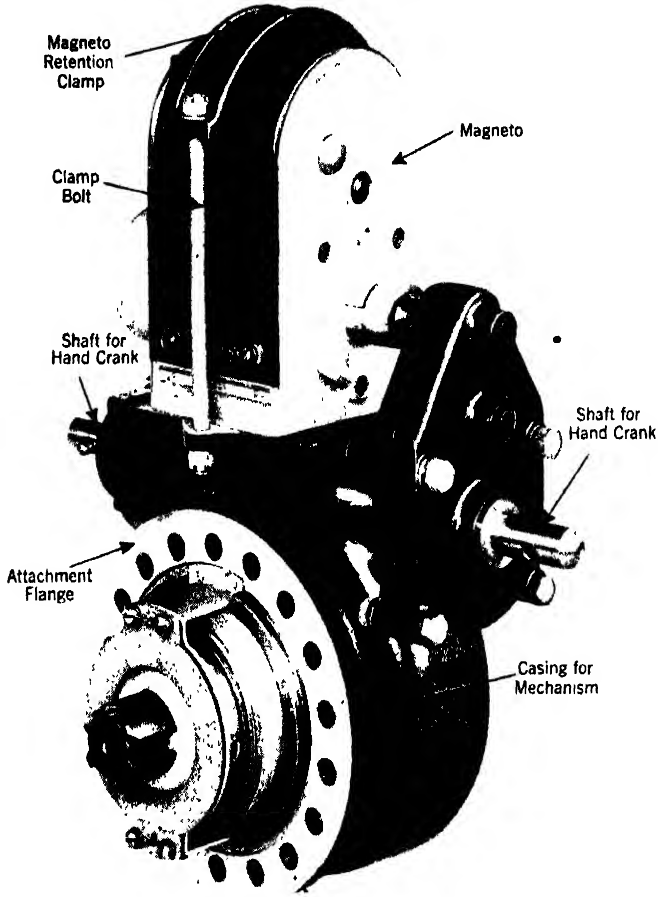


Fig. 191.—Eclipse Aviation Hand Starter with Booster Magneto Integrally Mounted.

Eclipse Aviation Engine Starters.—The Eclipse aviation hand starter with booster magneto is shown at Fig. 191. The gear ratio is 20 to 1 for engines up to 2,000 cubic inches displacement, 12 to 1 for engines up to 1,400 cubic inches and 6 to 1 for engines up to 900 cubic inches displacement. It may be applied to any aviation engine having a standard attachment plate. It has been fitted to the Liberty, Wright, Curtiss and other types of en-

gines. The weight complete with brackets, booster magneto and integral gearing is 28 pounds. The starter may be had without magneto if desired.

The hand starter consists of a gear reduction operating an automatic meshing and demeshing mechanism through an adjustable multiple disc clutch, operating in grease. The purpose of the multiple disc clutch is to provide a disconnection in the drive in case of engine backfire. Means are provided for preventing backward rotation of the handcrank at back-

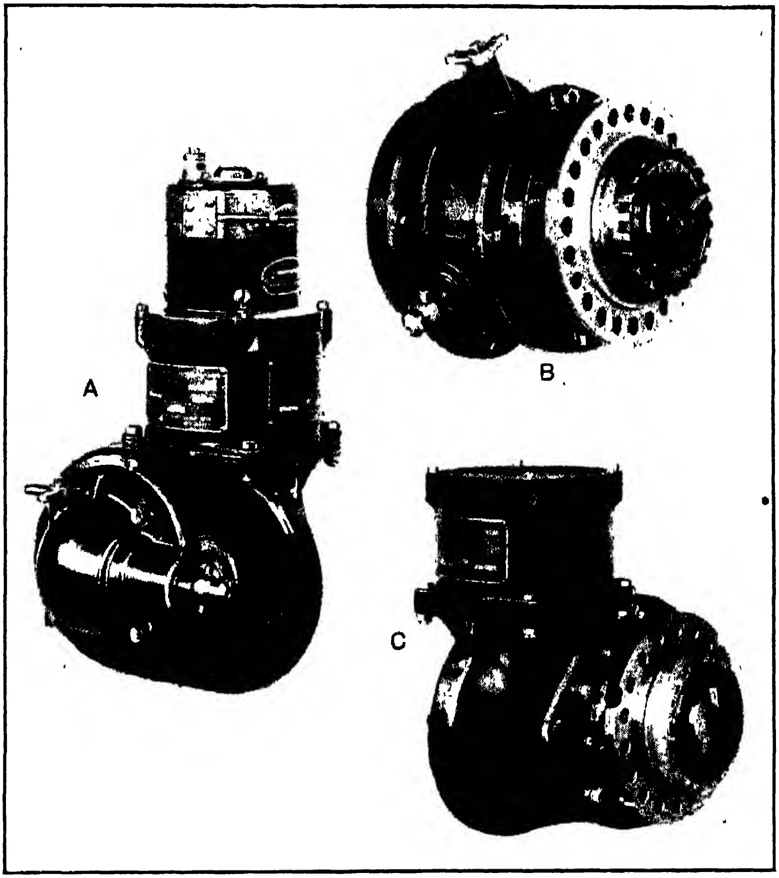


Fig. 192.—Eclipse Aviation Engine Starters. A—Combination Hand and Electric Inertia Starter. B—Hand Inertia Starter. C—Concentric Type Inertia Starter.

fire, thus preventing any possibility of injuring the operator. The automatic shift mechanism, as well as the backfire clutch are absolutely identical with the mechanism used in the Eclipse Aviation Electric Starter. The complete hand starter weighs 17 pounds.

Provision has been made to permit cranking from either side of the plane desired. A sufficient number of holes have been located in the mounting flange to permit a varied amount of angularity of the hand crank shaft, in order to place the hand crank in the most accessible position when applying the starter to the ship. Where hand magneto is desired, ar

attachment consisting of gearing, magneto bracket and hand magneto complete can be furnished for adapting to the standard hand starter. The advantage of this attachment lies in the fact that under normal conditions an operator cranking the hand starter at approximately 80 r.p.m. to the crank handle shaft will spin the magneto armature at approximately 1,000 r.p.m. The gear train transmitting rotation from the hand starter shaft to magneto armature is completely enclosed against entrance of dust.

Eclipse Hand and Electric Inertia Starter Series VII.—This starter shown at Fig. 192 A which operates on the principle of the storing of energy in a flywheel, was designed to fill the need for a light and efficient unit capable of cranking an airplane engine at high speed and satisfactorily starting the same during cold weather without the use of an auxiliary booster magneto, or like devices. The Series VII starter is recommended for use with engines of 2,500 cubic inch displacement, or smaller. The advantages of this type starter are obvious. The operator is enabled to make a start either on the ground or in the air merely by pressing a push button. This feature will be found particularly valuable in the case of a forced landing or with an engine stalling in flight. Cold weather starting is greatly facilitated because an instantaneous speed of approximately 125 r.p.m. of the engine crankshaft is attained, and this speed insures delivery of gas to the cylinders and also permits of starting with a fully advanced spark. Attached to a standard Liberty engine, five to six complete revolutions of the propeller are obtained from one loading of energy in the flywheel. The amount of current consumed is entirely independent of the stiffness or temperature of the engine, as the electric motor is merely used to accelerate a flywheel to a maximum speed of approximately 16,000 r.p.m., whereas in the electric starting motor type, the crankshaft is turned directly by the motor armature through gearing.

The starter as furnished can be operated at will either manually or electrically. If, however, electrical equipment is not contemplated on the plane, the starter can be furnished without the electric motor, as shown at Fig. 192 B a cover plate being mounted in its place. In such a case, however, the motor can be applied at a later time without any change other than the removal of the plate, and the applying of a motor, which is held in place by four screws. The weight of the combination unit is 35 pounds. Without the electrical attachment the weight is 27 pounds. Despite its remarkably light weight, the device is sufficiently rugged to operate satisfactorily indefinitely.

The flywheel is brought up to speed either manually or electrically, and the energy stored in same is released at the will of the operator by manually engaging it through a gear reduction drive, clutch and engaging mechanism with the crank shaft of the engine. The clutch is of the multiple disc type operating in grease, and can be adjusted for any predetermined torque to suit the engine to which the starter is applied. The purpose of this clutch is to provide a disconnection in the drive in case of engine backfire, thus effectively preventing damage to any part of the mechanism. The electric motor is arranged to automatically engage with the flywheel upon closure of the electric circuit, and to disengage when the circuit is broken, thus relieving the starter at all times of any losses due to

brush friction, particularly when hand cranking. The normal speed of the flywheel is 16,000 r.p.m. when accelerated electrically. This speed can easily be reached manually, and even exceeded. In some instances, however, it is possible to effect a start with a flywheel speed as low as 9,000 r.p.m. From this an idea can be formed of the amount of reserve power present when the flywheel is fully accelerated. The minimum speed to effect a start can be procured electrically in from two to four seconds time with a normal battery. From twelve to fourteen seconds is required to attain maximum flywheel speed. When accelerating by hand, maximum speed can be obtained in about one minute, depending upon the operator.

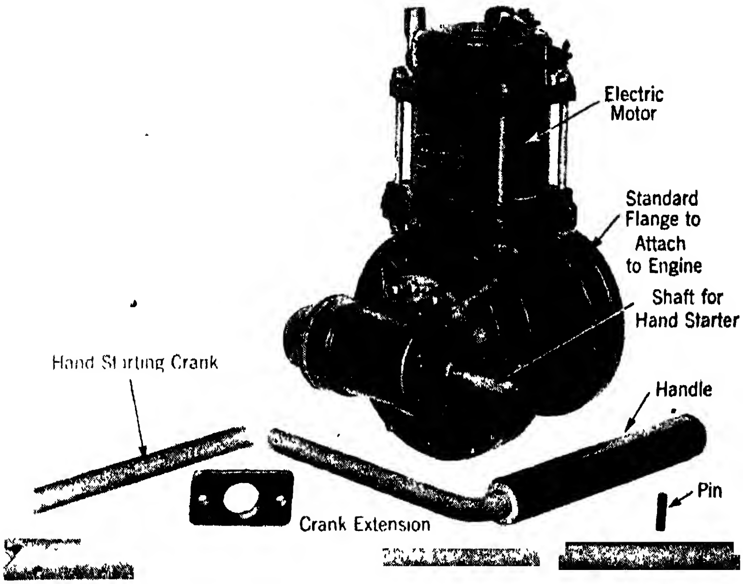


Fig. 193.—Eclipse Combination Hand and Electric Starter. Crankshaft can be Turned Either by Hand Crank of by Electricity from 12 Volt Battery.

The electric motor is designed to operate in conjunction with a 12 volt airplane type storage battery. The average current consumption is 120 amperes. Assuming that a 15 ampere, 15 volt generator is used at normal cruising speeds, an empty battery should be completely replenished in about two hours time. Application of the unit can be made to practically any existing type of engine. Eighteen holes, twenty degrees apart are located in the mounting flange of the starter to permit of mounting the same at almost any desired angle, thereby greatly assisting in its easy application. If desired, the starter can be mounted in a completely inverted position without affecting its operation in any way. Provision has been made for cranking by hand from either side of the plane as desired, and in addition the hand crank shaft can be varied through a fifteen degree angle, either upwards or downwards with respect to the center line of the starter. This feature, combined with the ability to rotate the starter at the mounting

flange, makes possible the location of the hand crank in the most accessible position when applying the starter to the ship. A manual hand crank with fixtures is furnished with each starter. Moving parts are completely enclosed and protected against ingress of dust. No lubrication of any kind is required, as the starters when shipped from the factory contain sufficient lubrication to last indefinitely. The inertia starter is also made in the concentric form as shown at Fig. 192 C, well adapted to radial engines.

Eclipse Electric Starter, 12 Volt.—This starting motor shown at Fig. 193 has been designed to mount at the ignition end of the Liberty 12-cylinder engine, and is also applicable to such engines as the Curtiss, Wright and Packard, etc. The application of this type of starter has been considered standard by aviation engine manufacturers, and almost all of them are building their engines to receive this starting motor. This motor is furnished as a combination electric and hand unit. If desired as an electric starter only, it can be furnished without the hand attachment. Practically all of the installations of this starter are in the form of the combined electric and hand unit. The starting motor operates in conjunction with a suitable 12 volt battery, of a size depending upon capacity, as well as other uses to which the battery may be put. Batteries are obtainable in weights ranging from 35 pounds to 70 pounds. Detailed information on batteries may be obtained direct from the battery makers.

The unit will crank a standard 12-cylinder Liberty engine at a speed of approximately 30 r.p.m. It consists of a small electric motor geared at a ratio of 100 to 1, the power of which is transmitted to an automatic engagement mechanism merely by closing an electrical switch contact. Disengagement is also effected automatically when the engine fires. A backfire release mechanism in the form of a multiple disc clutch is incorporated in the starter to prevent damage to the driving mechanism in the event of a backfire. It is designed, in the form shown for engines of 2,000 cubic inches displacement or smaller.

A hand crank attachment has been incorporated in the design of this device, such that should a storage battery not be available, the device may be used as a suitable hand crank, giving a reduction of approximately 20 to 1, and using the same automatic meshing and demeshing mechanism, as well as backfire damage prevention device, as when the device operates as an electric starter. Means have also been provided for preventing backward rotation of the hand crank in case of backfire, thus preventing any possibility of injury to the operator. This hand crank attachment has been designed so that the engine can be cranked from either side, and by turning the crank handle in either direction, merely by the interchange of parts when assembling the hand crank unit. For outboard engine installation, that is for multi-engine airplanes or airships, a magnetically-operated, remote control solenoid switch and pilot push button switch are provided. This saves starting cable weight and makes for complete control of the electrical starting equipment within reach of the pilot. In addition to this, multi-engine ships may be operated from a single battery. The total weight of the complete unit is 34 pounds. The above unit is suitable for engines up to 450 horsepower. Provision has been made for applying a

larger electric motor with additional weight of 4½ pounds for engines in excess of 450 horsepower.

The Bristol Gas Starter.—The Beardmore engine shown at Fig. 184 is said to be easily started by the Bristol gas starter, despite its large size. The starter consists of a small air-cooled, single-cylinder, two-cycle engine driving a pumping cylinder that draws a supply of gasoline vapor and air from the carburetor of the starter engine and delivers it under pressure to the cylinders of the main engine. The delivery of the mixture to the latter is controlled by a small disc-valve distributor driven from the main engine at half the crankshaft speed and arranged so that the mixture enters the cylinders, first on the firing stroke and secondly for a part of the induction stroke. To avoid the loss of pressure which would occur from the escape of gas through the open inlet valves on the induction stroke, the port in the distributor is first closed during this period by a spring-loaded mushroom valve, but when the main engine begins to turn freely, a hand lever is raised to open the valve referred to, gas then being admitted on the induction stroke. After a complete revolution in this condition, the cylinders and the whole of the induction system are thus filled with gas. Although the starter engine has only one cylinder, it is fitted with a two-cylinder type magneto and the second ignition lead is connected to the distributor of the magneto of the main engine. For the first part of the starting operation, this second lead is short-circuited, but when the main engine is turning freely and has been filled with gas as described, the short-circuiting switch is opened and the engine then fires and picks up on its own carburetors. A non-return valve is fitted in the starter connection to each cylinder of the main engine to isolate the starter when the engine is running normally.

The starter will maintain a gas pressure of 140 pounds per square inch, and it is capable of starting high-speed gasoline engines with cylinder capacities up to 2,500 cubic inches or slow-speed oil engines up to 5,000 cubic inches capacity. An important feature of the arrangement is the fact that the only connections between the main engine and the starter are a small-bore pipe and a high-tension lead, and it is thus possible to locate the starter in any convenient position up to 20 feet from the engine. The weight of the starter unit is 50 pounds, so that it is suitable for use with aircraft engines, and, as the starter engine can be run continuously without overheating, it can be used for driving auxiliaries such as wireless generators at such times that the plane is not in flight a very convenient thing if a large seaplane was forced to alight away from shore or a commercial airplane had to land in a remote locality. The small generators are usually driven by small air propellers that will turn only when the airplane is in flight.

Air Starting System.—The "Christensen" air starting system which has been used in airships in the original or modified form is shown at Figs. 194 and 195. An air pump is driven by the engine, and this supplies air to an air reservoir or container attached to the fuselage. This container communicates with the top of an air distributor when a suitable control valve is open. An air pressure gauge is provided to enable one to ascertain the air pressure available. The top of each cylinder is provided with a

check valve, through which air can flow only in one direction, i.e., from the tank to the interior of the cylinder. Under explosive pressure these check valves close. The function of the distributor is practically the same as that of an ignition timer, its purpose being to distribute the air to the cylinders of the engine only in the proper firing order. All the while that the engine is running and the car is in motion the air pump is functioning, unless thrown out of action by an easily manipulated automatic control.

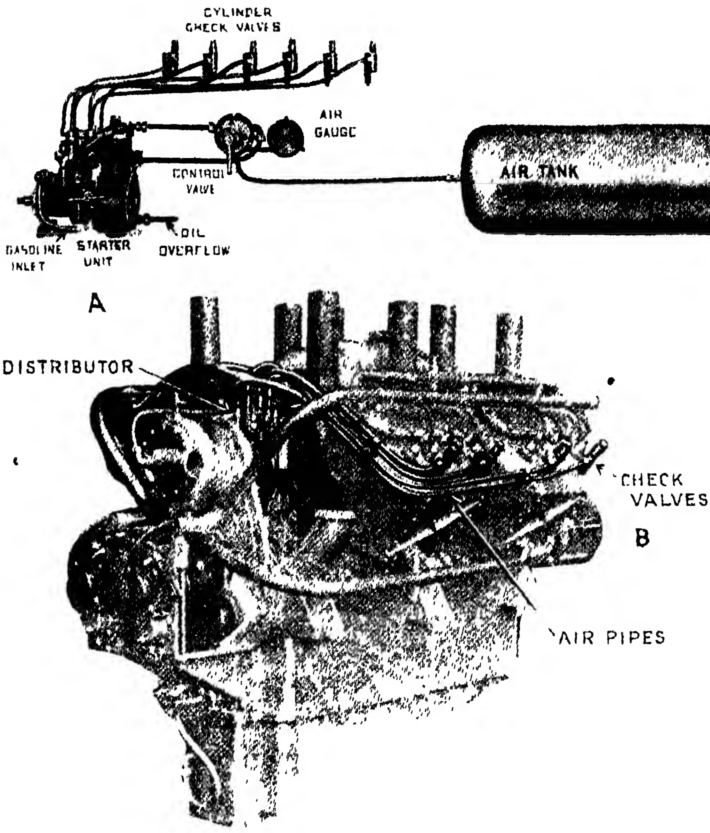


Fig. 194.—Parts of Christensen Air Starting System Shown at A and Application of Piping and Check Valves to Cylinders Outlined at B.

When it is desired to start the engine a starting valve is opened which permits the air to flow to the top of the distributor, and then through a pipe to the check valve on top of the cylinder about to explode. As the air is going through under considerable pressure it will move the piston down just as the explosion would, and start the engine rotating. The inside of the distributor rotates and directs a charge of air to the cylinder next to fire. In this way the engine is given a number of revolutions, and finally a charge of gas will be ignited and the engine start off on its cycle of operation. To make starting positive and easier some gasoline is injected in

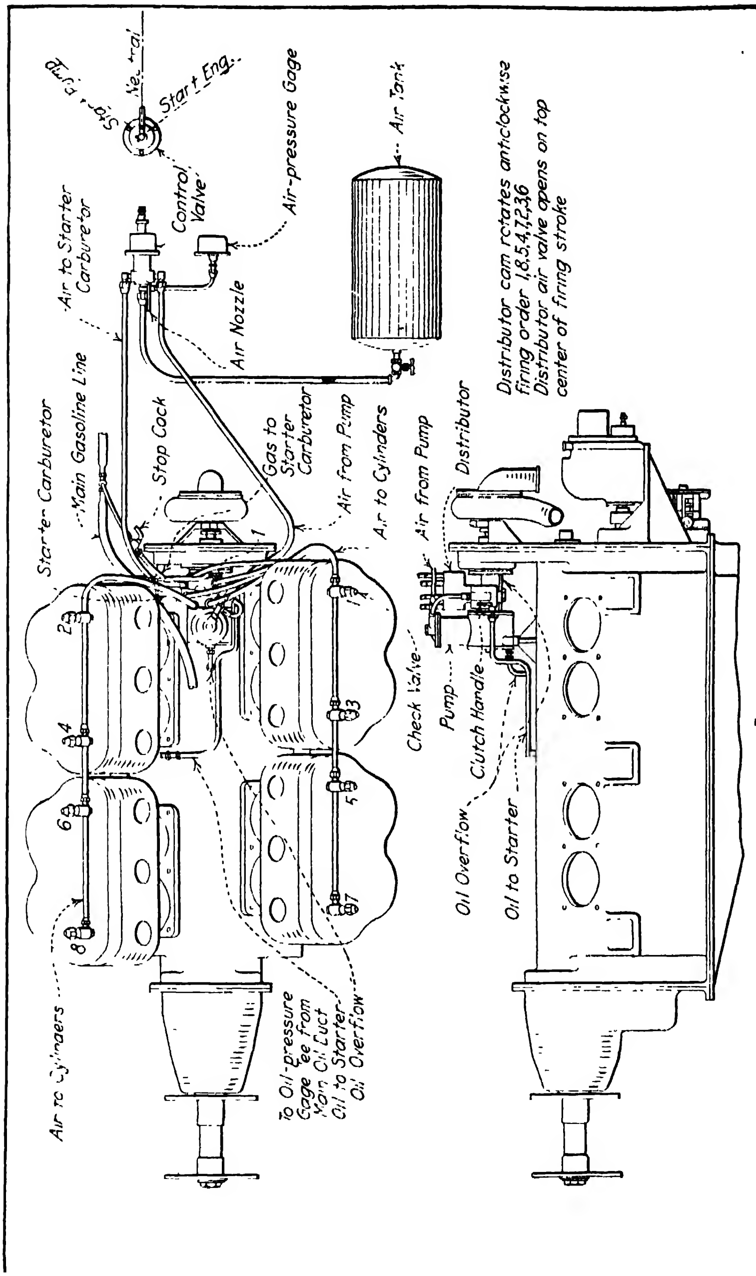


Fig. 195.—Diagrams Showing Installation of Air Starting System on Large Aviation Engines.

with the air so an inflammable mixture is present in the cylinders instead of air only. This ignites easily and the engine starts off sooner than would otherwise be the case. The air pressure required varies from 125 to 250 pounds per square inch, depending upon the size and type of the engine to be set in motion.

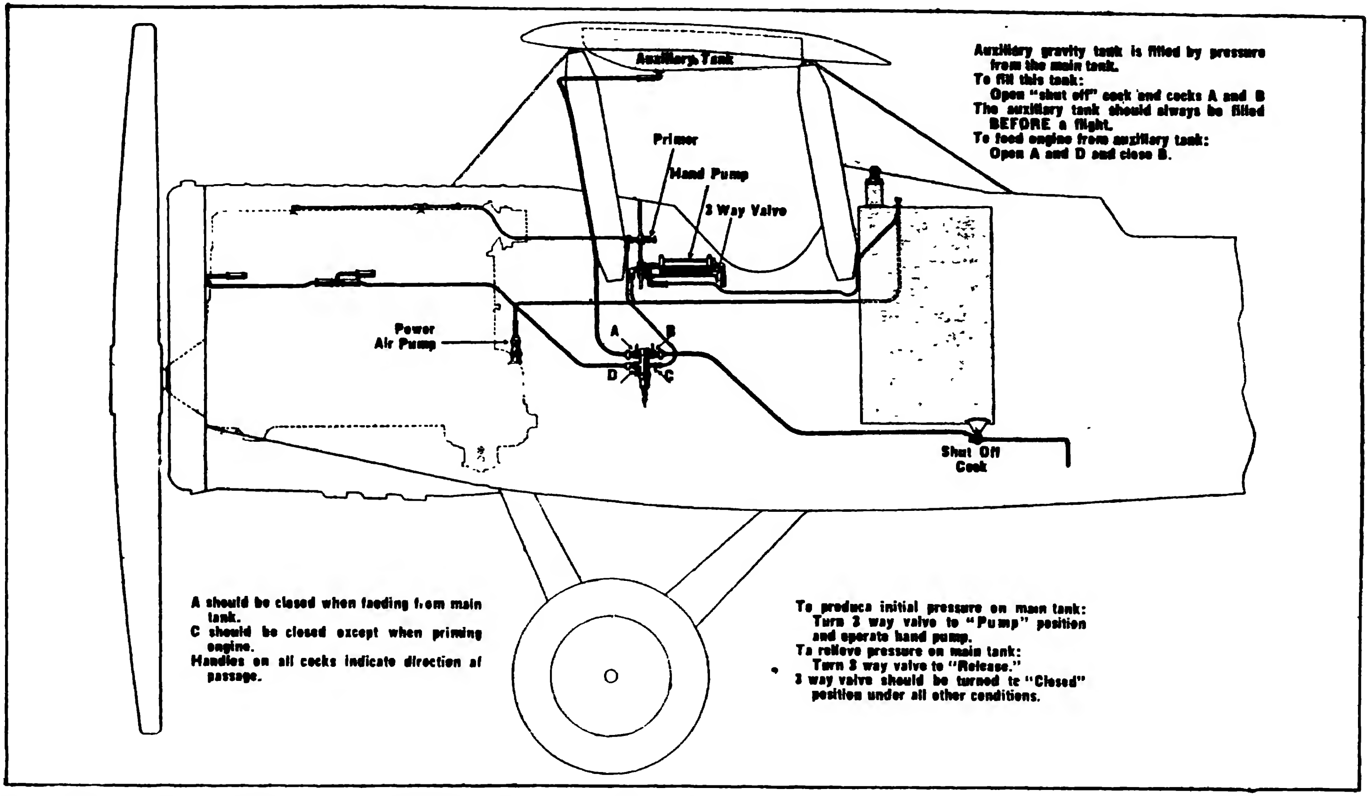


Fig. 196.—Fuel Supply System of Early Model DH 4 Airplanes Using Liberty Engines in which Gasoline was Displaced by Air Pressure in Main Tank.

Fuel Tanks and Supply Systems.—The problem of gasoline storage and method of supplying the carburetor is one that is determined by design of the airplane, the desired cruising range and amount of engine power supplied. While the object of designers should be to supply the fuel to the carburetor by as simple means as possible the fuel supply system of some airplanes is quite complex. The first point to consider is the location of the gasoline tank. This depends upon the amount of fuel needed and the space available in the fuselage.

A very simple and compact fuel supply system may be used on training planes. In this instance the fuel container is placed immediately back of the engine. The carburetor which is carried lower than the engine or tank is joined to the tank by a short piece of copper or flexible tubing. This is the simplest possible form of fuel supply system as gravity is employed to supply the fuel.

As the sizes of engines increase and the power plant fuel-consumption augments it is necessary to use more fuel, and to obtain a satisfactory flying radius without frequent landings for filling the fuel tank it is necessary to supply large containers, some of which may be carried below the engines.

When a very powerful power plant is fitted, as on battle planes of high capacity, it is necessary to carry large quantities of gasoline. In order to use a tank of sufficiently large capacity it may be necessary to carry it lower than the carburetor. When installed in this manner it is necessary to force fuel out of the tank by air pressure or to pump it out with a hand or wind driven suction pump to auxiliary tanks from which the feed may be by gravity because the gasoline tank is lower than the carburetor it supplies and the gasoline cannot flow from the main tank by gravity as in the simpler systems. The pump feed systems are generally used in airplanes at the present time.

The fuel system of the DH4 airplanes shown at Fig. 196 is typical of installations where fuel is displaced by air pressure from the main tank to an auxiliary tank in the center section. Two air pumps are used, one driven by the engine, the other by hand. In the type shown the main tank is carried back of the forward cockpit, a not entirely desirable location which was afterwards changed by putting it immediately back of the engine. A special fitting is used by which fuel may be supplied to the carburetors from the auxiliary tank or from the main tank. The hand pump is used to produce initial pressure on the main tank and fill the auxiliary tank by air displacement. Normally, the three-way pump valve is turned to the closed position. While in flight, the engine driven air pump supplies the air to the main fuel tank. Sometimes fuel is tranferred from a main tank to auxiliary tanks by air propeller driven fuel pumps supplemented by hand pumps.

The sectional view of the "Pathfinder," an airplane built by the Keystone Aircraft Corporation for trans-oceanic flight and provided with three Wright Whirlwind motors shown at Fig. 197 depicts how fuel and oil tanks are installed in a plane intended for long distance flights. As deep section aerofoils are used, it is possible to use large wing tanks in the upper wing.

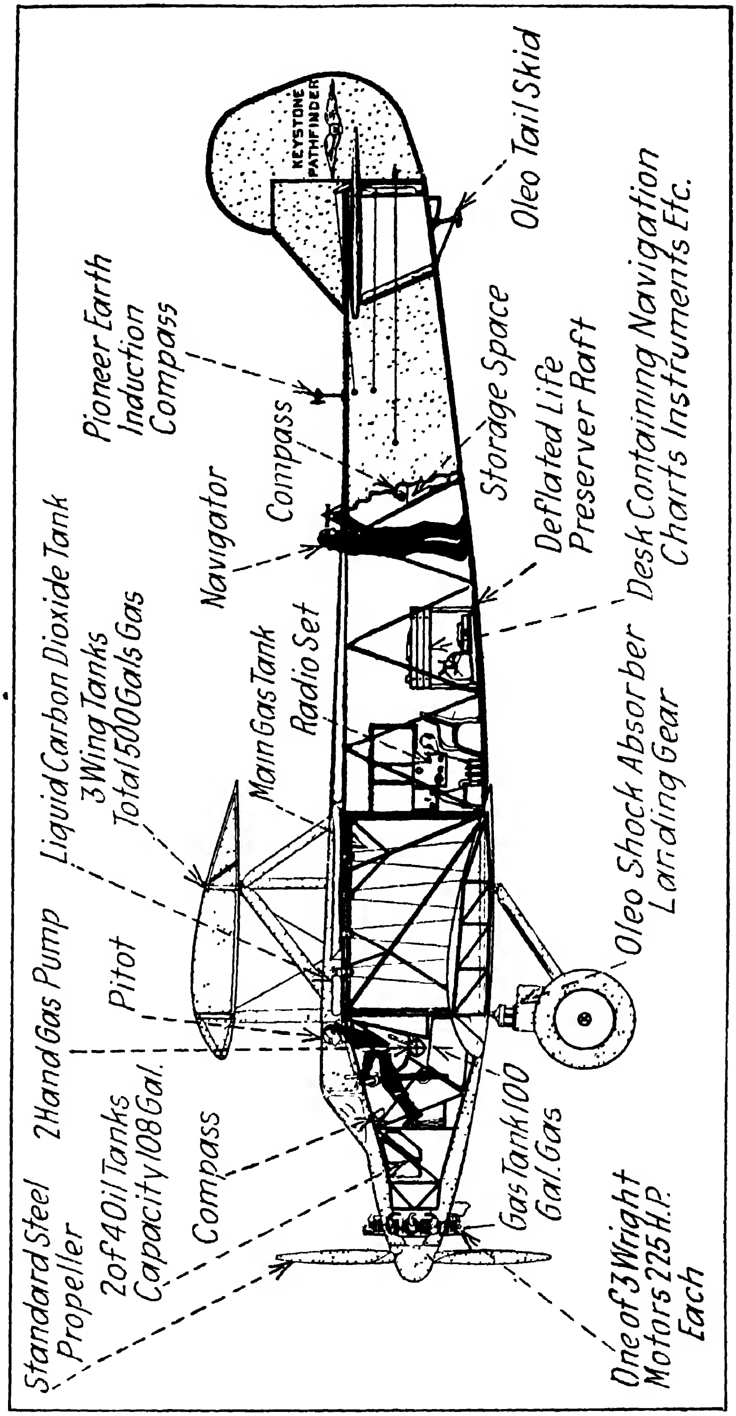


Fig. 197.—Fuel Tank Location in Keystone Pathfinder Biplane.

Three fuel tanks with a capacity of 500 gallons in all are mounted in the aerofoil. Directly back of the pilot's compartment is a large tank capable of holding 900 gallons and a small tank capable of holding 100 gallons is situated under the pilot's seat. This makes a total of 1,500 gallons which will give the plane a range of 4,500 miles, or an air endurance of about 50 hours. For normal commercial use, the large tanks in the fuselage are eliminated and this space is devoted to passengers or freight. The fuel capacity is thus reduced to enough to cruise 1,500 miles, which means an air endurance of about 15 hours. Four oil tanks are provided, with a total capacity of 108 gallons.

The system of fuel supply involving pressure in the supply tanks to transfer the fuel is not universally favored because there is more danger of leakage and a consequently greater fire risk than when there was only atmospheric pressure in a vented tank. Modern airplanes depend on engine driven fuel pumps to deliver fuel from the main tanks directly to the carburetors in some instances, in others, the mechanical fuel pumps deliver the gasoline to auxiliary tanks, from which fuel feed to carburetors is by gravity. When pressure is carried in the main tank, any slight leak around a rivet or in a soldered seam permits more fuel to escape than would be the case in a vented tank.

During the War and for some time afterward, an air pressure system was used to supply fuel to the carburetors. A small engine-driven air pump maintained a pressure of 2 to 4 pounds per square inch on the tanks. Air pressure on the tanks constituted a very serious fire hazard in the event of a crash. The large tanks must be of very light construction and are therefore fragile. In the case of a burst tank, the air pressure caused gasoline and vapors to be sprayed around in the debris with almost a certainty of some of it finding its way to the hot exhaust stacks. At present, it is general practice to lead the fuel from the tank through a hand pump, which can be operated by the pilot in case of necessity, to a very small engine-driven fuel pump. This pump delivers the gasoline directly to the carburetors at a pressure of from 4 to 5 pounds per square inch. A small spring-loaded valve is used to regulate the pressure and the overflow is returned to the tank. This overflow cannot be returned to the suction side of the pump through a regurgitating valve because, at great altitude, the fuel becomes highly volatile and many bubbles are formed in the supply line, and if returned to the supply air bubbles would cause the pump to become airbound.

Duralumin Fuel Tanks.—When airplanes were first built, light gauge tinned copper was employed for fuel tanks, and brass and terneplate were also used. The reason for using these materials, despite their great weight, was that the tanks were of relatively small capacity and could be easily soldered at the joints and seams. As fuel tanks became larger, lighter materials were sought as the cuprous and ferrous metals or alloys were much too heavy. Duralumin has been successfully employed for fuel tanks by the Curtiss Aeroplane and Motor Company and other constructors; but through the discovery of a new plating process, it is possible to solder the material instead of welding it as was necessary in the past.

Inability to solder aluminum satisfactorily forced the use of a welded construction on these tanks. This type of construction was extremely difficult and expensive, and the appearance of the finished product was not highly satisfactory. In addition, service difficulties developed: a sediment formed which interfered with the gasoline flow; leaks were frequent, and repairs in the field were difficult—in fact, almost impossible. In spite of these drawbacks, aluminum tanks have come to be extensively used in aircraft, solely because of their great weight advantage. It is interesting to note that probably the first aluminum tanks to be used in this country were those built by the Curtiss Company and installed in the NC boats, one of which, in 1919, made the first flight across the Atlantic, via the Azores.

Realizing that the ideal type of tank would be one which would combine the lightness of the aluminum type with the low cost and excellent service features of the brass tank, the Curtiss Company set about to develop such a tank, and, after a great deal of research and experimentation, has produced a duralumin tank. The special nickel-plating process was developed by William J. Travers, of Buffalo, N. Y., and Curtiss is the sole aeronautical licensee. Plated duralumin tanks, therefore, can be made by the same methods as brass tanks, which means ease and low cost of manufacture. They stand up well in service, develop no deposit to interfere with fuel flow, and, if damaged, can be repaired easily with an ordinary soldering iron. Combined with these advantages is the extremely low weight of the duralumin.

The importance of this weight saving can easily be seen when one realizes that on the Curtiss Hawk pursuit plane, a saving of about 45 pounds has been realized by making the gasoline and oil tanks of duralumin instead of brass, and this saving would, of course, be increased in larger machines. Since the weight carried by the Hawk is 6½ pounds per horsepower, the saving of 45 pounds means that 7 horsepower has been released to do useful work in propelling the airplane. Plated duralumin tanks have undergone all kinds of service tests for the past two years, and have shown up so satisfactorily that all tanks now being made by the Curtiss Company, including those for the U. S. Army and Navy Hawks and the Army Falcons, are of plated duralumin. These tanks are also being manufactured by the Curtiss Company for the trade.

Aircraft Carburetors.—Aircraft carburetors operate under extreme variations of temperature and pressure. The atmospheric conditions vary, not only with season and weather, but also with altitude. The variation of temperature and pressure with altitude is very wide and requires a correspondingly wide range of mixture control. Since the mixture given by a carburetor becomes lean with increasing density, the fuel metering orifices must be large enough to take care of the highest density at which the engine will operate. A manual control is provided to weaken the mixture for lower densities. At a 20,000 foot altitude it is stated the mixture would be 50 per cent too rich with sea level adjustment.

Fig. 198 shows the types of control usually used. At A is shown a control which varies the pressure in the float chamber. A number of carburetors are easily synchronized by connecting the float chambers with balancing tubes. At B is shown a very successful type of control which

admits air between the venturi throat and throttle valve. Since a large amount of air is handled by the valve, slight mechanical variations do not appreciably interfere with synchronization of the valves on several carburetors. The controls shown are all designed for hand adjustment, which requires experience on the part of the pilot and the controls are not always properly handled. Some experimental work has been accomplished to the end of developing an automatic aneroid mechanism which will operate the mixture control.

Another condition under which the aircraft engine carburetor must operate is the extreme variation from the horizontal position. Smooth engine operation must be maintained in climbs, dives and side slips. This is met by careful location of the float chamber in relation to the fuel

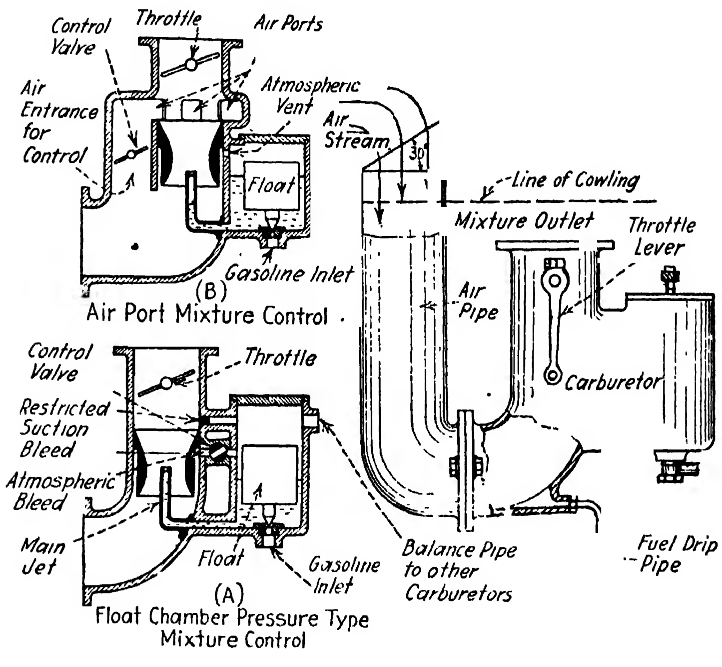


Fig. 198.—Types of Altitude Control Used for Carburetors. A—Float Chamber Pressure Control. B—Air Port Mixture Control. C—Air Intake for Airplane Carburetor.

nozzles and metering orifices. On single carburetors the float chamber is located at the side, or the annular type is used. The most up-to-date duplex carburetors mount the float chamber between the two barrels, or have a U-shaped float chamber partially surrounding them.

In order to reduce fire hazard, the carburetor air intakes should project outside the engine cowling and fuel drip pipes should lead any fuel leaking due to "flooding" away from the engine, especially the exhaust gas discharge. This means that the aircraft carburetor must take its air from a slipstream travelling at a rate of from 100 to 200 m.p.h., which constitutes another problem in carburetion peculiar to aircraft service. For general

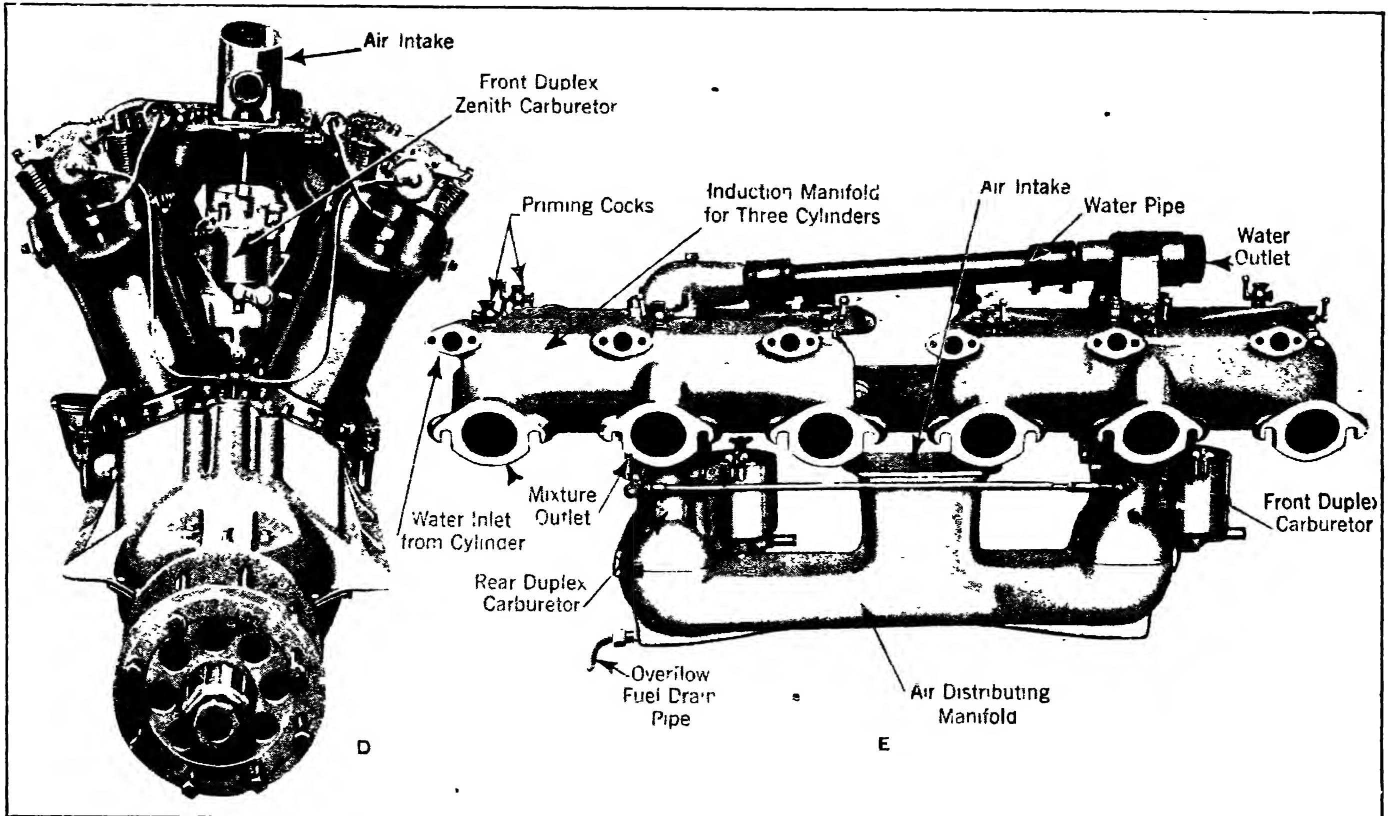


Fig. 198, con't—D—How Carburetor is Mounted on Liberty Engine between Cylinder Banks. E—Carburetors and Induction Manifolds of Liberty Airplane Motor Removed from Cylinders.

service the air intake, as shown at Fig. 198 C and D, is satisfactory, but for extremely high-speed airplanes it is better that the air intake face directly forward.

The Zenith carburetor, shown at Fig. 199, has become very popular for airplane engine use because of its simplicity, as mixture compensation is secured by a compensating compound nozzle principle that works very well in practice. To illustrate this principle briefly, let us consider the elementary type of carburetor or mixing valve, as shown in Fig. 200 A. It consists of a single jet or spraying nozzle placed in the path of the in-

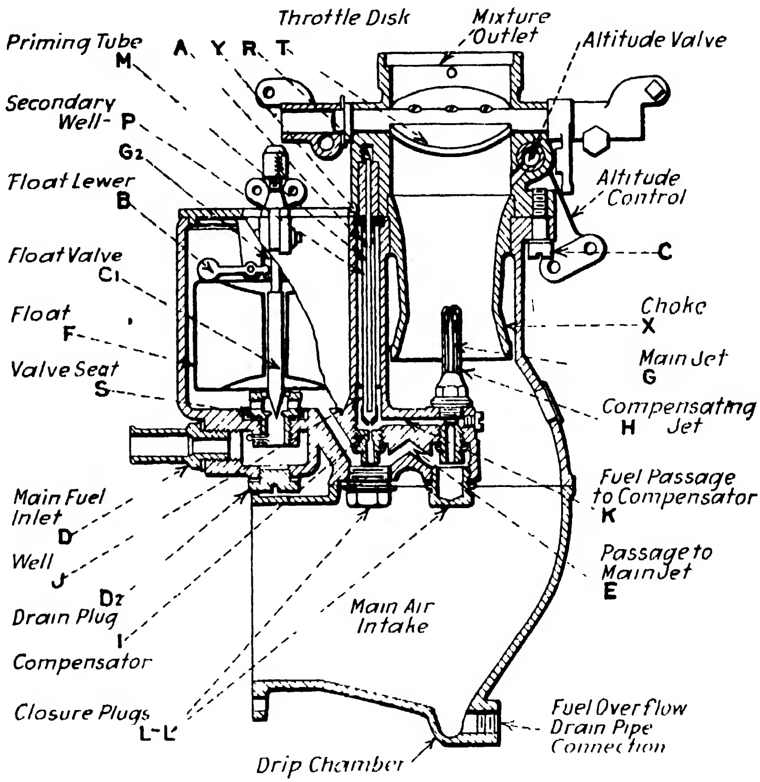


Fig. 199.—Section of Zenith Duplex Carburetor Used with Liberty Engines.

coming air and fed from the usual float chamber. It is a natural inference to suppose that as the speed of the motor increases, both the flow of air and of gasoline will increase in the same proportion. Unhappily, such is not the case. There is a law of liquid bodies which states that the flow of gasoline from the jet increases under suction faster than the flow of air, giving a mixture which grows richer and richer—a mixture containing a much higher percentage of gasoline at high suction than at low. The tendency is shown by the accompanying curve (Fig. 200 B), which gives

the ratio of gasoline to air at varying speeds from this type of jet. The mixture is practically constant only between narrow limits and at very high speed. The most common method of correcting this defect is by putting various auxiliary air valves which, adding air, tends to dilute this mixture as it gets too rich. It is difficult with makeshift devices to gauge this dilution accurately for every motor speed.

Now, if we have a jet which grows richer as the suction increases, the opposite type of jet is one which would grow leaner under similar conditions. Baverey, the inventor of the Zenith, discovered the principle of the constant flow device which is shown in Fig. 200 C. Here a certain fixed amount of gasoline determined by the opening I is permitted to flow by gravity into the well J open to the air. The suction at jet H has no effect upon the gravity compensator I because the suction is destroyed by the open well J. The compensator, then, delivers a steady rate of flow per unit of time, and as the motor suction increases more air is drawn up, while the amount of gasoline remains the same and the mixture grows poorer and poorer. Fig. 200 D, shows this curve.

By combining these two types of rich and poor mixture carburetors the Zenith compound nozzle was evolved. In Fig. 200 E, we have both the direct suction or richer type leading through pipe E and nozzle G and the "constant flow" device of Baverey shown at J, I, K and nozzle H. One counteracts the defects of the other, so that from the cranking of the motor to its highest speed there is a constant ratio of air and gasoline to supply efficient combustion.

With the coming of the double motor containing eight or twelve cylinders arranged in two V blocks, the question of good carburetion has been a problem requiring much study. The single carburetor has given only indifferent results due to the strong cross suction in the inlet manifold from one set of cylinders to the other. This naturally led to the adoption of two carburetors in which each set of cylinders was independently fed by a separate carburetor. Results from this system were very good when the two carburetors were working exactly in unison, but as it was extremely difficult to accomplish this cooperation, this system never gained in favor. The next logical step was the Zenith Duplex, shown in its simplest form at Fig. 201. This consists of two separate and distinct carburetors joined together so that a common gasoline float chamber and air inlet could be used by both. It does away with cross suction in the manifold because each set of cylinders has a separate manifold. One Duplex carburetor is satisfactory for an eight-cylinder V engine but two duplex carburetors have been found necessary on 12-cylinder V engines, each mixing chamber being joined to a manifold serving three cylinders as shown at Fig. 198 E.

The altitude adjustment of the Zenith Aeronautical Carburetor is illustrated diagrammatically at Fig. 202 A and as applied to the carburetor used on Liberty engines at Fig. 202 B. The float chamber is open to the air through two screened air inlets. The well J is in open communication at its top with the float chamber. A passage P is provided from the float chamber to the carbureting chamber below the throttle valve, this passage is fitted with a stop cock L which is manually operated from the pilot's

seat. Under normal conditions, i.e., near the ground the stop cock should be closed. The fuel in the float chamber will be subjected to atmospheric pressure through screened air inlets. When the engine is running, the partial vacuum produced in the choke X will draw fuel out of nozzles G and H in proper proportions. When an altitude of 6,000 feet is reached, the pilot will begin opening the valve L, thus drawing air from the float chamber and establishing a partial vacuum therein, this depending upon the amount the valve L is opened. The partial vacuum or suction effect on top of the gasoline in the float chamber will reduce the flow through the

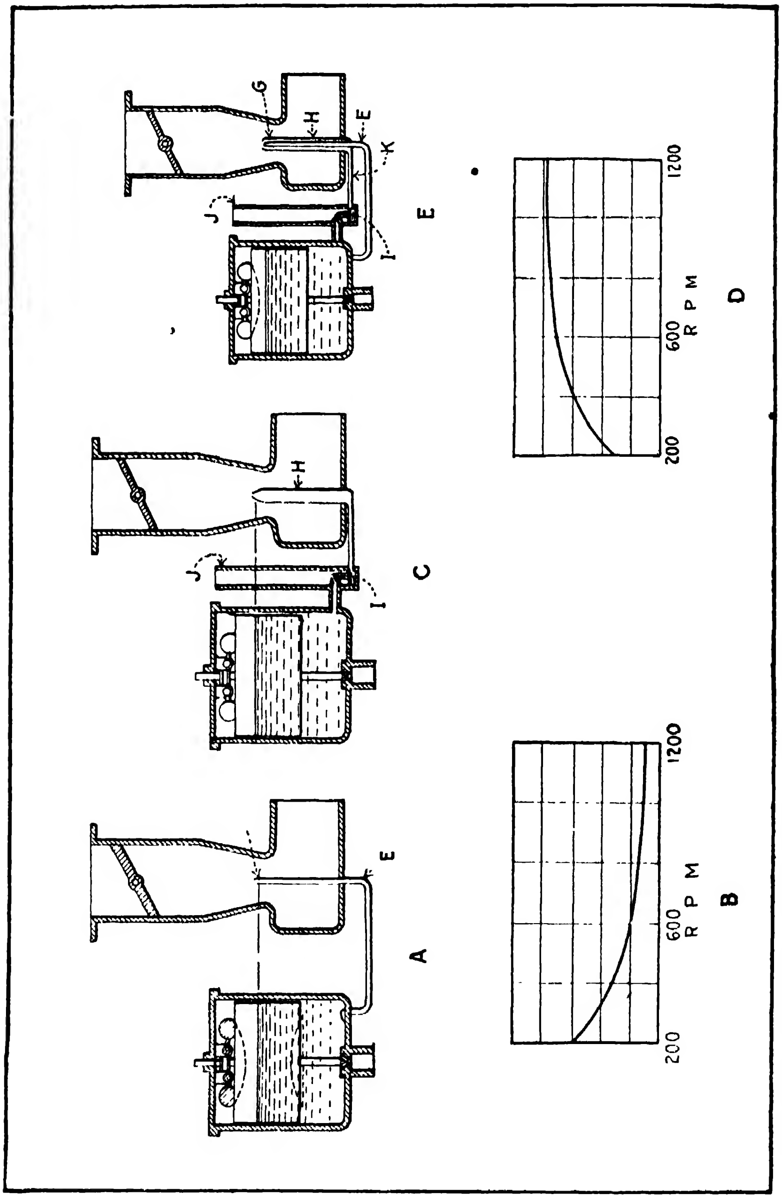


Fig. 200.—Diagrams Explaining Action of Bavary Compound Nozzle Used in Zenith Carburetor.

jets because of its retarding effect and the mixture will become more lean. The altitude valve should be opened as much as possible without its producing a drop in revolutions of the engine.

The size of the three variables, Choke Tube, Main Jet and Compensator that determine mixture proportions has been carefully determined by the engine builders and **should not be changed** except under extreme con-

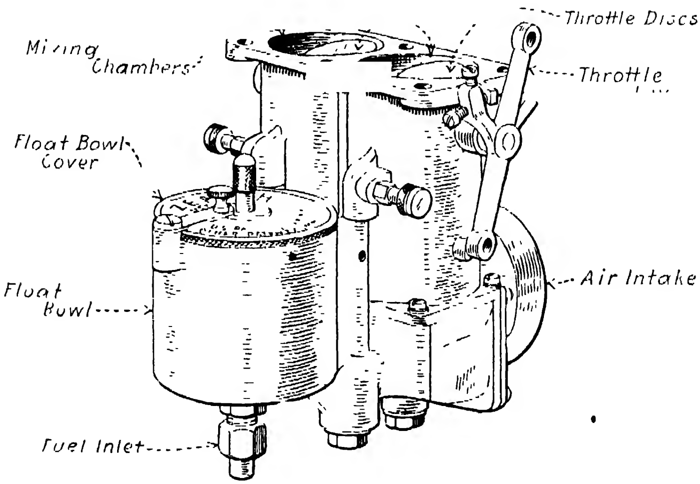


Fig. 201.—The Zenith Duplex Carburetor for Airplane Motors of the V Type.

ditions. The numbers stamped on each of these parts indicate the size. The chokes are numbered according to the smallest inside diameter in millimeters. The jets and compensators are numbered according to the diameter of the opening in hundredths of a millimeter. For instance, a No. 105 jet has a hole 1.05 millimeters in diameter. The choke and jet sizes which have been found to give the best results on Liberty "12" engines are:

Choke	No. 31
Jet	No. 145
Compensator	No. 155
Idling Jet	No. 70

Airplane Engine Superchargers.—An examination of some of the present day engines and a review of the descriptive matter preceding would lead one to the opinion that, in the light of current knowledge of materials, a further important reduction in the specific weight of conventional four-stroke-cycle engines is hardly to be expected without sacrificing durability unless there be some radical change in design not at present contemplated. Therefore, with due regard for continued improvement along these lines and for the possible development of engine types that are radically different from the present accepted standards, it would seem that one of the most logical fields for improvement of the aircraft engine would be the bettering of its altitude performance.

Considerable data dealing with the altitude performance of the internal-combustion engine has been published, and it is not planned to discuss this phase of the problem in this treatise to any extent. It is enough to call attention to the fact that, as the power developed in the cylinders of the internal-combustion engine is directly proportional, other conditions being constant, to the weight of charge burned in a unit of time, it naturally follows that the power developed at altitude, for a constant engine speed, will decrease approximately in direct proportion with the decreased air-density; the brake, or effective, power decreasing somewhat more rapidly due to the fact that certain of the friction losses remain constant. Thus, an engine will develop somewhat less than one-half its sea level power under altitude conditions of one-half air-density, or at an altitude about 20,000 feet because the weight of mixture taken into the cylinders is only

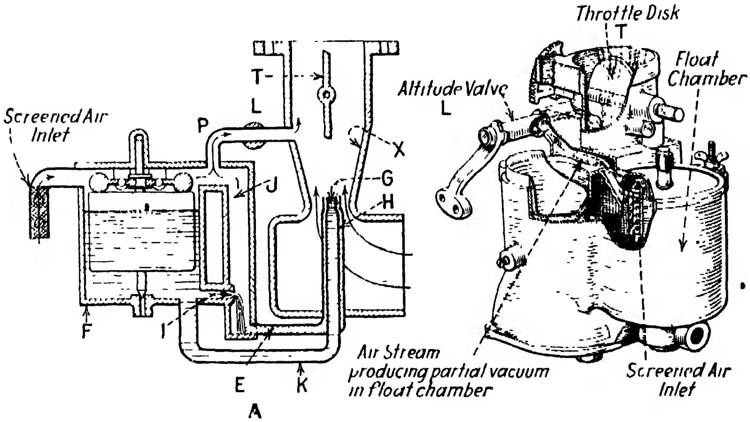


Fig. 202.—Diagrams Showing Altitude Control in Zenith Aviation Engine Carburetor. A—Showing Principles Involved. B—Practical Application to Zenith-Liberty Carburetor.

half that inspired at sea level. The air gets less dense or thinner the higher we go. On the basis of power developed at high altitude, supercharging, as defined by the maintenance of sea level density of the air supplied to the engine, unquestionably is superior to the other methods. Whatever may be the particular advantages of supercharging, it would seem to have a definite application in the future development of aircraft engines. In reviewing the supercharger developments it will be noted that attention for the most part has been directed toward developing the high-speed centrifugal-type air-compressor, whereas not so much consideration has been given to the positive displacement rotary-type compressor, although it possesses some merit for supercharging service. The Roots compressor, belonging to the latter class, has been used to some extent as a supercharger on automobile engines, notably on the Mercedes automobile engines and on racing engines in Europe and in this country.

With a normal engine, the falling off in power as the plane ascends does not result in as much of a reduction in propeller speed as might be thought,

because of the diminished density of the air in which the propeller is working. It is stated that some engines do not lose over 75 r.p.m. at 20,000 feet. When an engine is supercharged so that the power remains constant as the plane ascends, the propeller tends to "race" at great altitudes. Therefore it is necessary either to use a variable-pitch propeller or install one that holds the engine speed down too low for best performance on the ground but that does not allow the engine to race too much at great altitude.

It is already common practice to build aviation engines with compression so high that the throttle cannot be fully opened on the ground without injury to the engine. This practice is not objectionable because the engine is intended for flight purposes and not for operation at sea level. In this way the same power is obtained at 5,000 feet as can be obtained on the ground. It has been suggested that this idea be carried further and that an "oversize" engine be built with much higher compression so the throttle cannot be opened fully until a considerable altitude, such as 10,000 or 15,000 feet, is reached. It has been stated that such an engine could be made lighter, in proportion to the cylinder sizes, than a conventional engine, on account of the fact that the throttle would never be opened near the ground, but it is believed that when this idea is investigated, it will be found that it is the inertia forces quite as much as the explosion forces that determine the necessary strength in most high-speed airplane engine parts and that therefore such an engine could not be built light enough to make it practical. In any case, it is doubtful whether this would give a really good solution for flying at 25,000 or 30,000 feet.

Supercharging, as the term is generally used, means forcing a charge of greater volume into the cylinder than that which is normally drawn into the cylinders by the suction of the pistons in conventionel internal-combustion engines. At 25,000 feet altitude less than 25 per cent of sea level power is delivered. If air is supplied to the carburetor at sea level pressure or approximately 14.7 pounds per square inch absolute at high altitudes the power developed by the engine becomes about the same as when operating at sea level. The low atmospheric pressure and density at great altitudes offer reduced resistance to high airplane speeds; hence the same power that will drive a plane at a speed of 120 m.p.h. at sea level will drive it much faster at 20,000 feet, and still faster at 30,000 feet altitude, *and with approximately the same consumption of fuel per horsepower hour*, providing the area of the aerofoils and pitch of propeller are such as needed in the thinner air.

Superchargers usually take the form of a mechanical blower or pump and, of course, require a driving gear of some kind. The types of blowers or compressors used to date include the reciprocating, Root displacement and centrifugal types. When the Roots type is employed, as shown at Fig. 203 A some form of receiver is necessary to equalize the pulsating nature of the discharge. This form, when driven by positive gearing, may be timed so its greatest pressure may be coincidental with the induction stroke of the cylinder. The reciprocating type of pump is only suited for slow speed Diesel engines as it is much too heavy for airplane service.

The turbo-compressor shown at Fig. 203 B in which an exhaust-driven turbine is used for driving the centrifugal compressor, seems at first thought to present a practical way of accomplishing the desired purpose. The turbo-compressor itself is very simple, as there is only one moving part, namely the rotating element consisting of the turbine wheel and com-

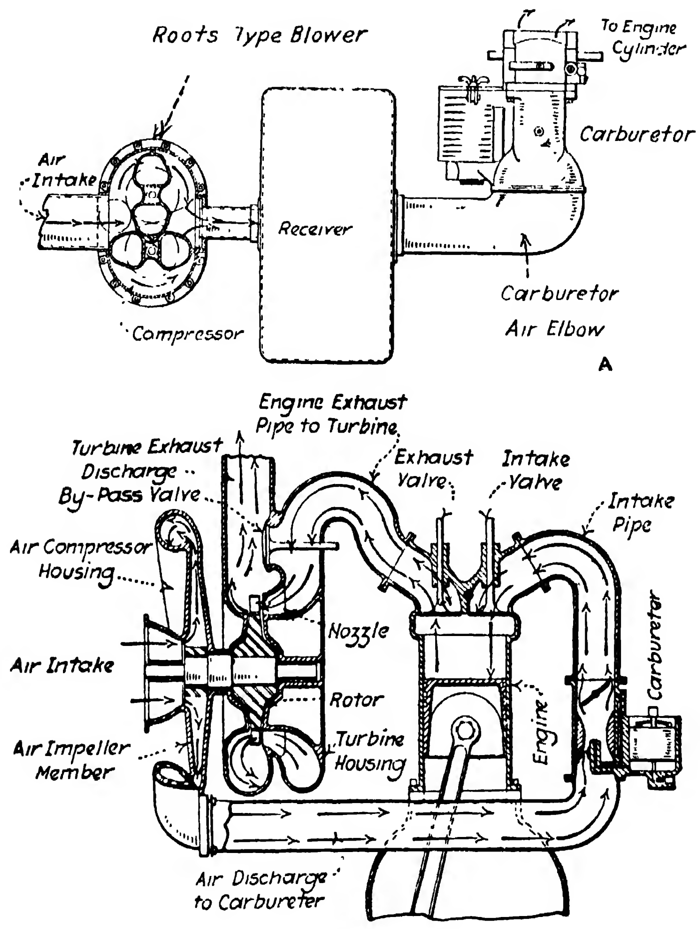


Fig. 203.—Simple Diagrams Showing Main Types of Airplane Engine Superchargers. A—Root's Blower, a Positive Displacement Type. B—Exhaust Driven Centrifugal Compressor.

pression impeller. The bearings of this rotating element do not seem to wear noticeably and the device imposes very little drag on the engine when not being used for supercharging. The turbo-compressor is also an effective exhaust muffler. The difficulty with devices of this character are due to troubles in the turbine caused by the high temperatures of the exhaust gases passing through it which affected the strength of the materials comprising the turbine and resulted in turbine failures. The power obtained

from the exhaust gas is not always sufficient to deliver the required volume of air, so gear driven forms have been devised.

Fig. 204 A is a diagram of an impeller, a diffuser and a collecting passage or scroll. The air enters at the center against vanes designed to receive it without shock. At the periphery of the impeller there is a certain pressure due to centrifugal force which is about one-half or two-thirds of the final pressure. The air at the periphery of the impeller is moving at a high velocity also, although velocity is of no particular value because it is much higher than the velocity in the pipe which receives the final air.

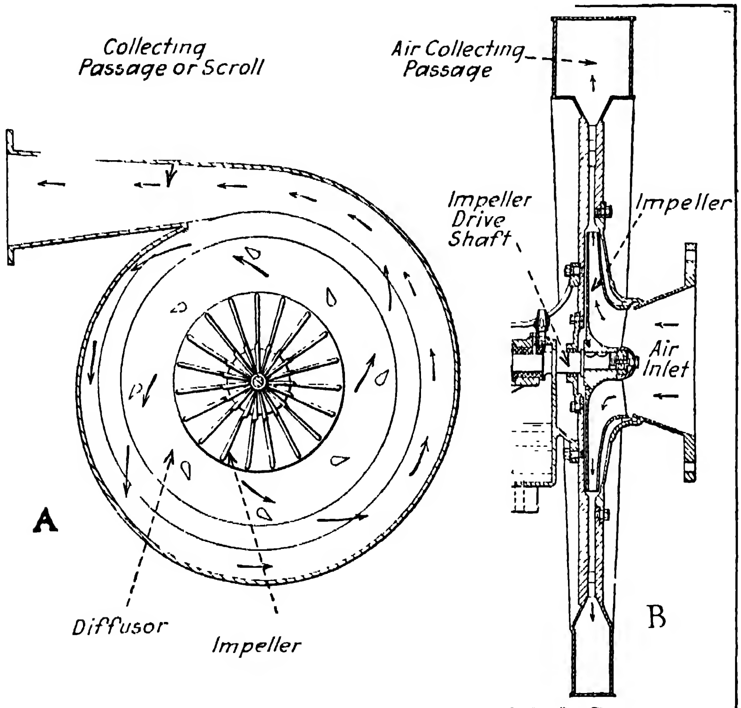


Fig. 204.—Types of Centrifugal Compressors. A—Vane Impeller Type. B—General Electric Type.

However, the velocity represents power that has been put into the air, and the problem is to transform this power, represented by velocity, into power represented by pressure which can be used. The diffuser does this. The diffuser slows down the air so that the velocity is decreased and, if this process is accomplished effectively, a rise in pressure will result. In other words, at the beginning of the diffuser passage the air has a certain pressure and considerable velocity. It passes through the diffuser, which gradually decreases the velocity and increases the pressure. The blower portion of a centrifugal compressor which will give pressures up to 30 pounds is shown at Fig. 204 B. It will be apparent that the impeller member is of entirely different construction than that shown at A. This is the General Electric type. The compressor having a single inlet is used for

smaller volumes but for large volumes of air, it is necessary to take in air at both sides of the impeller.

Turbo-Superchargers.—The first work on turbo-superchargers was done by Professor Rateau in France. In 1917, at the suggestion of Dr. Durant, the Government selected Dr. S. A. Moss of the General Electric Company to develop a similar supercharger in this Country. Dr. Moss designed the Form-A supercharger which was tested on Pikes Peak, and which was used by Major Schroeder in making his first world's altitude record with a supercharged airplane. Further development of the turbo-supercharger and of the present side-type turbo-supercharger is the work of Government engineers at McCook Field, assisted by the manufacturing facilities of the General Electric Company. The various developments were conceived at McCook Field, where all the practical testing was carried out, and the preliminary drawings were made under the direction of Government engineers.

The first gear-driven supercharger submitted to the Air Service, aside from the development work carried out in the American Expeditionary Force by M. LeBlanc and Captain Kerr, was a vane blower by Pense, which was not successful. The next was a gear-driven centrifugal-compressor designed by H. E. Morton, of the B. F. Sturtevant Company. This supercharger was a very interesting design that incorporated an oil clutch to reduce the acceleration load on the impeller.

The first gear-driven supercharger of the type now in use was designed by McCook Field engineers, and this development resulted in the present geared superchargers of 10,000 and 20,000 feet altitude rating used by the Air Service. The General Electric Company then submitted a geared supercharger with a double step-up gear-drive consisting of three sets of gears mounted in plain bronze-bearings. The compressor part was of conventional design, but so much trouble was experienced with the geared drive that the design was discarded. The successful development of geared superchargers was brought about by the development of light weight aluminum alloys for the impellers and by the development of anti-friction bearings that will operate successfully at speeds of 30,000 r.p.m. Reducing the moment of inertia of the moving parts is of the utmost importance.

The original turbo-superchargers had impellers made of steel. When the first Air Service gear-driven design was made, a similar impeller made of forged duralumin was used. The next step in lightening the impeller was to scallop between the blades. Then, forged magnesium was used successfully. Although of less strength than forged duralumin, the strength-weight ratio is nearly the same, and it is on this ratio that the factor of safety of the impeller depends. Later, an impeller was made of cast magnesium, and this also proved amply strong. It is evident that it will soon be possible to make impellers of die-cast magnesium, requiring practically no machine work to finish. The Aluminum Company of America and the American Magnesium Company were of great assistance in carrying out the development of impeller material. Ball bearings and roller bearings continually failed at speeds around 20,000 r.p.m.; but, after 3 years of testing at McCook Field, ways of mounting and lubricating the

bearings have been developed so that they have operated more than 200 hours at speeds above 30,000 r.p.m.

Roots Blower.—The Roots blower which was first developed commercially in 1859 is of the type generally known as the positive displacement rotary, and consists essentially of two rotors, having two lobes each, which are rotated in opposite directions at the same speed within a case composed of two halves of a cylinder separated by the center-distance between the rotors (see Figs. 203 A and 205). The lobes of one rotor fit

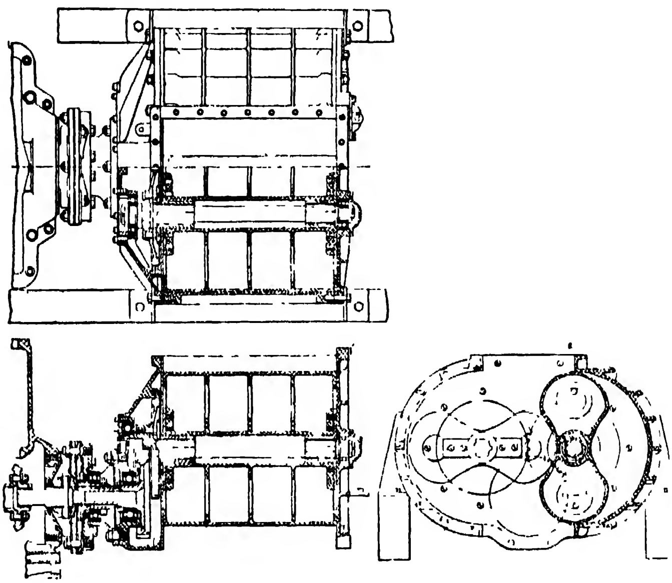


Fig. 205.—Sectional Views of Root Blower for Liberty Engine Supercharging.

into the recesses in the mating rotor and are held in correct relation by timing-gears located at one end of the rotor shafts. Clearances are maintained at all points between the rotors and between the rotors and the case, to avoid internal friction and assist in obtaining high mechanical efficiency. The contour of the rotors, which are usually hollow metal castings, is made up of sections of epicycloid and hypocycloid curves, and thus, being mathematically correct for proper mesh, the clearances can be made uniform and small. The rotors are mounted on separate shafts, one of which takes the main drive; the other is driven through the timing-gears. These shafts usually are carried in plain bearings in the commercial types.

Following its development for commercial use, it has been used, both for handling liquids and compressing air, in that type of service where it was required to deliver relatively large volumes against moderate pressure-heads, the economical range, as regards delivery pressures, being arbitrarily set at from 8 ounces to 8 pounds per square inch. Below 8 ounces the centrifugal type is usually employed, and above 8 pounds the reciprocating

pump or compressor is regarded as the more economical for the reason that leakage in the Roots type increases and, when handling air, the compression efficiency decreases with an increase in delivery pressure. The commercial compressors, or blowers, usually are operated at rotor-speeds up to 800 r.p.m., depending on the size, with the maximum speed of probably 850 r.p.m., while those used for supercharging airplane engines have been operated at speeds up to 5,000 r.p.m. or over six times normal commercial speeds.

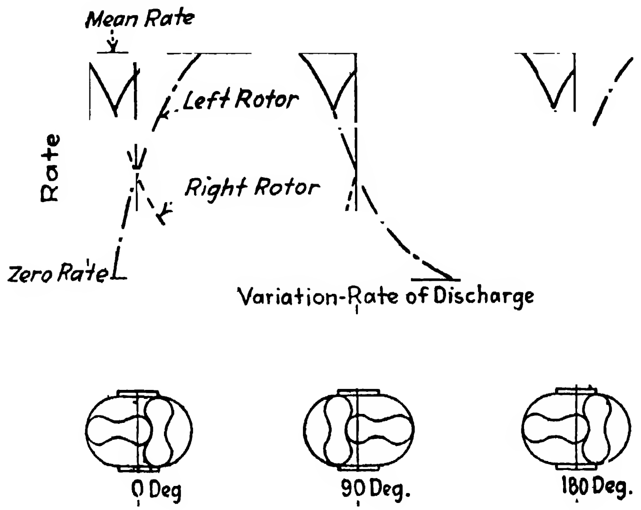


Fig. 205.—Diagram Showing Variation of Rate of Discharge for Root Blower for Varying Positions of Rotor Members.

The Roots compressor gives a continuous but non-uniform rate of delivery, as represented by the curves of Fig. 206. These curves, which show the rate of delivery for each rotor and the combined rate for both rotors, with no compression, are drawn for the Roots supercharger developed for the National Advisory Committee for Aeronautics, the rotors of which are not full cycloidal in contour. Rate-of-delivery curves for full-cycloidal rotors would be similar. The sectional views at Fig. 205 show an experimental Roots blower built for the Liberty engine. Interesting details are the oil-baffle at the rear of the engine; the taperpin in the coupling, designed to shear when subjected to excessive torque and thereby permit uninterrupted engine operation in the event of supercharger failure; the drive and timing-gears; the splined rotor-hubs, the tongues of which are set into recesses milled in the ends of the rotors and fastened to the rotors with screws; the transverse ribs in the rotors to prevent distortion of the rotor shell at high speeds; the thin section of the rotor shell; and the method of locating the rotor in the compression chamber by locating the

outer races of the rotor shaft bearings. As seen from this illustration, the rotors are hollow castings and are driven by their respective shafts through splined steel hubs. The views at Fig. 207 shows the external appearance of a Roots blower at A; with end plate removed to show rotors at B and the arrangement of the driving gearing and rotor drive shafts at C. The volumetric efficiency at 2,800 r.p.m. with rotors 11 inches long was 98 per cent. The amount of power consumed by such a blower depends upon the method of supercharger output control and the speed of rotor rotations against varying air pressures. For example, at an altitude of 16,000 feet, with a rotor speed of 2,000 r.p.m., delivering 1 pound of air per second the energy required is about 40 horsepower.

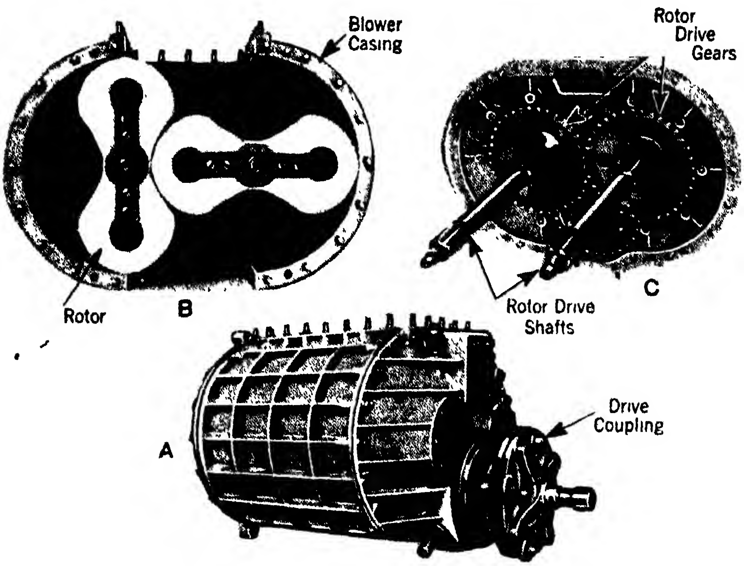
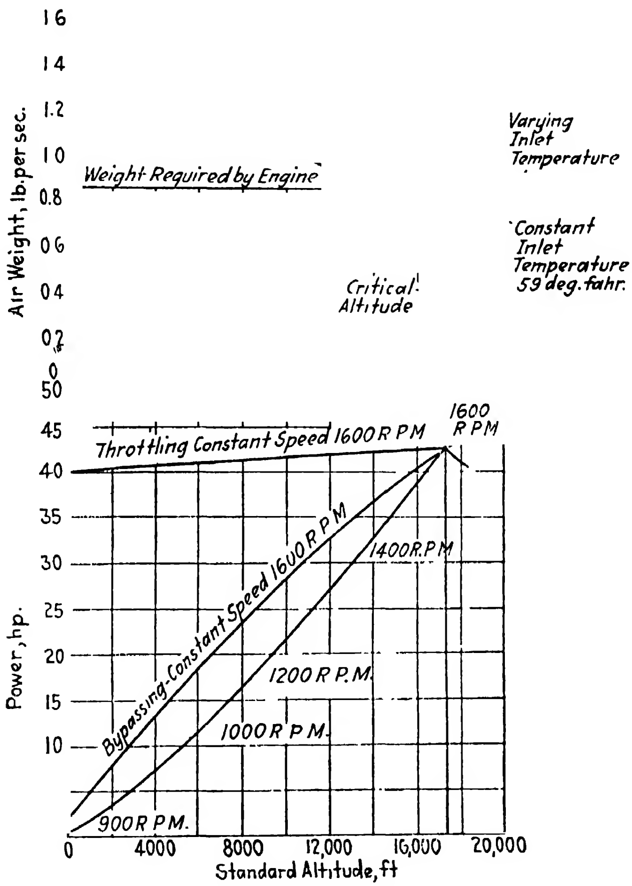


Fig. 207.—View at A Shows Root Supercharging Blower Assembly. B—End Plate Removed to Show Rotors. C—End Plate and Rotor Drive Gears and Shafts.

There are three methods of supercharger control; that is, varying the speed of the supercharger to maintain a constant air weight to the engine, maintaining a constant supercharger speed and by-passing the excess air at low altitudes into the atmosphere and throttling the intake to the supercharger to maintain a constant air weight to the engine. The case is taken for the Liberty-12 engine operating at 1,600 r.p.m., and the assumption is made that the air weight required by the engine will be the same at all altitudes. This assumption is incorrect owing to the fact that the volumetric efficiency of the engine will increase with altitude due to the difference in pressure between the engine intake and exhaust, and for the reason that the increase in temperature of the compressed air will reduce the air weight that the engine can induct. The assumption is accurate enough, however, for comparative purposes. The upper curves of the graphic chart shown at Fig. 208, reproduced from the S. A. E. Journal give the air weight

handled by the supercharger at a constant speed at altitude both for the condition of constant inlet temperature and of varying inlet temperature. The intersection of the air weight handled by the supercharger with the weight required by the engine establishes what is termed the critical altitude, or highest altitude at which full pressure can be maintained at the carburetor.

In the lower group of curves it will be seen that, to supply the engine with a constant air weight, the speed of the supercharger drive shaft,



POWER REQUIRED WITH THREE METHODS OF SUPERCHARGER CONTROL.

Fig. 208.—Diagrams Showing Power Required for Three Methods of Supercharger Control when Root's Type Blower is Used.

geared 1.5 to 1.0, must be varied from 900 r.p.m. at sea level to 1,600 r.p.m. at the critical altitude. This gives the ideal method of control but is difficult of attainment. The curve immediately above represents the power required at a constant drive shaft speed of 1,600 r.p.m., by the method of by-passing, and shows, from the standpoint of power required, the ap-

proach to the ideal; the power required is the same at the critical altitude. The extra power required by this method is a direct function of the extra volume of air handled and the difference in supercharger friction. The temperature of the air supplied to the engine is the same for these two methods of control, due to the fact that the air is compressed the same amount in both cases. The third method of control, throttling the intake to the supercharger, besides being wasteful of power at the lower altitudes, results in excessive heating of the air supplied to the engine at low altitudes. The power required by this method approximates, in relative units, that required by the gear driven centrifugal compressor; and the heating of the air in the case of the latter is even greater than would obtain in the Roots supercharger under similar conditions.

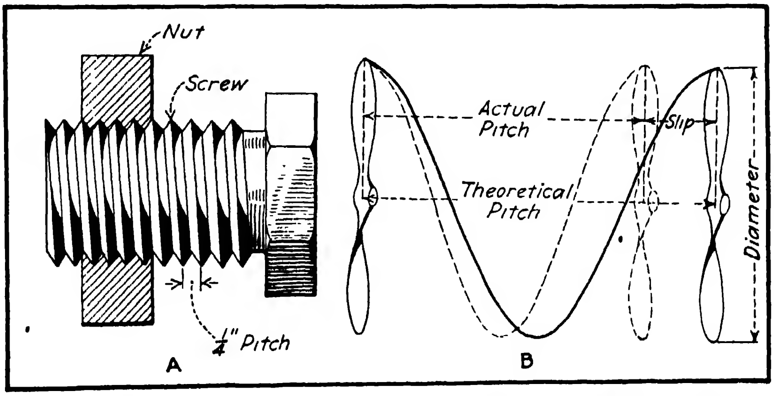


Fig. 209.—Diagrams Explaining Pitch of Aerial Screw Propeller.

The following advantages are advanced by proponents of the Roots blower for supercharging purposes. It can be built in sizes and operated at speeds that make it suitable for aeronautic use. It has a high efficiency even in small, high-speed sizes. Its characteristic fluctuating discharge can be taken care of in installation and is not detrimental to engine operation. It is simple and rugged in construction. The engine can be operated as a normal engine by leaving the by-pass control open. There is no need of clutch control or change-over valves. The temperature of the discharged air is lower, for the same degree of compression, than when delivered by a centrifugal compression. Due to its relatively low-speed of operation, this being from one-tenth to one-fifth the speed of a centrifugal compressor, extreme care in balancing is not needed, air friction losses are small, the speeds of rotation are well within the range of ball bearings with normal installation and lubrication and the gear drive problem, introduced by conditions of rapid acceleration, is not as serious as in the very high-speed types. This form has the disadvantage of greater bulk and weight than a centrifugal supercharger of equal capacity.

The advantages obtained by installing superchargers are not obtained without some disadvantages. The weight and mechanical complication of the power plant is increased, it being stated that a supercharger installa-

tion suitable for an engine weighing 850 pounds and delivering 600 horsepower will augment the weight by 150 pounds. Then one must consider the power required by a supercharger. That used on Liberty and similar engines, regardless of type require from 30 to 60 horsepower, depending upon variable operating conditions. Despite these disadvantages, the use of a supercharger is the best method of attaining high altitudes without using engines of great excess power when operated at sea level. With this in mind, tests have shown that the indicated absolute ceiling, with full supercharging maintained to 20,800 feet, has been increased about 92 per cent, the service ceiling about 100 per cent, and the time to climb 16,000 feet reduced from 32 to 19 minutes.

QUESTIONS FOR REVIEW

1. Describe oil temperature control system and its advantages.
2. What is an "inertia" starter and how does it work?
3. Describe electric starting means for aircraft engines.
4. Outline difference between gas and compressed air starters.
5. Describe fuel supply systems of modern airplanes.
6. What are the disadvantages of pressure feed by compressing air in the fuel tank?
7. Describe typical airplane engine carburetor.
8. How is compensation obtained in carburetors for different altitudes?
9. What is a supercharger and what does it do? How is a supercharger controlled?
10. What is the difference between a turbo-supercharger and a Roots blower?

CHAPTER XI

AIRCRAFT PROPELLER CONSTRUCTION AND ACTION

Principle of the Screw—When Screw Works in Air—Mathematical Consideration of Propeller Pitch—Theories of Screw Propeller Action, Disc Theory—The Blade Theory—Propeller Definitions—Wood Propeller Manufacturing Practice—Propeller Made of Laminations—Shaping the Blades—How Wooden Propellers are Balanced—Propeller Storage and Maintenance—Mounting Propellers—Fitting New Hub to Shaft—Wood Propellers of Thin Laminations—Bakelite Propellers—How Bakelite Propellers are Made—Tests of Bakelite Propellers—Difficulties with Wood Propellers—Wood Propeller Tip Protection—Table XIX, Centrifugal Force of 1 Sq. Inch of Sheet Copper for Various Weights, Radial Distances and Revolutions Per Minute—Pigskin Tips—Fabric Tips—Metal Propellers—Leitner-Watts Steel Propeller—Screw Overlap in Multi-Engine Types—Variable Pitch Propellers—The Dicks Propeller—Levasseur Propeller—Hart and Eustis Variable Propeller—Epicycle Airplane Propeller Drive Gears—Universal Adjustable and Reversible Propeller—Features of Reed Duralumin Propeller.

The principle of the screw was applied by Archimedes, the Grecian mathematician, in raising water as early as 200 B. C., and the screw or helical rotating propeller has been associated with proposed methods for the propulsion of aerial craft for four or five centuries by inventors who had the genius of conception but who were handicapped by not having a light and powerful engine, as we have today to drive their propellers. The original screw propeller was of the single worm type, having but one thread, and could hardly be compared with the present form. That we may properly appreciate the functions of the screw propeller we have an excellent demonstration of the principles involved in the bolt and nut, with which all are familiar.

Principle of the Screw.—A screw is a cylinder having a spiral ridge or thread around it, which cuts at a constant oblique angle all the lines of a surface parallel to the axis of the cylinder. A hollow cylinder, called a nut, having a similar spiral within it is fitted to move freely upon the thread of the solid cylinder as shown at Fig. 209 A. For simplicity we will consider that there are four ridges or threads to the inch. Obviously, if the nut was held stationary, in four complete turns the screw would advance or recede an inch if the screw were turned toward the right or left. On the other hand, we will assume that the nut is so held that it can travel only back and forth and not around when the screw is turned. Four complete turns of the screw would produce a movement of one inch, one complete turn would move the nut one-quarter inch. This distance is the pitch of the screw, as the definition is: The pitch of a screw is the distance through which the screw would advance in one revolution, provided that it revolved in an unyielding medium, such as a solid nut.

It will be evident that if the thread of the bolt were of such depth to offer sufficient area that considerable resistance would be offered to its backing in or coming out of a more flexible medium in which the bolt was

submerged, such as water, that the water surrounding the threads would act to a certain extent as a nut, and assuming erroneously for simplicity of explanation that this did not move either backward or forward, as would be the case were the nut of resisting material held immovable, it may be seen that revolving the bolt would tend to exert a thrust which would produce either forward or reverse movement of the bolt. This is the principle of the screw propeller whether it operates in air or a denser medium, such as water. The less the density of the fluid in which the propeller is submerged, the greater the area of blade or thread surface necessary to exert the same thrust.

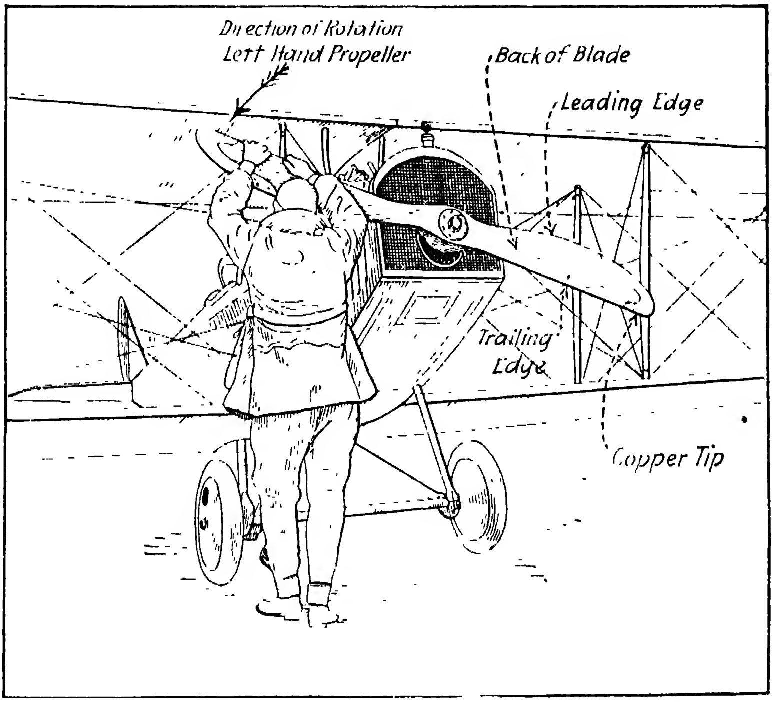


Fig. 209A.—Direction of Turning when Priming Engine Fitted with Aerial Screw that Turns Left Hand, or Anti-clockwise, when Viewed from Front of Airplane. If Considered from Viewpoint of Pilot, this Would Be a Right-Hand Screw.

If the screw is mounted in such a way that it is continuously revolved, it will produce a continuous movement. For instance, assuming that the bolt has a pitch of one inch and that it worked in an elastic medium less resistant than solid substances of which nuts are usually made: As it is turned there would be two effects: the bolt would move forward, and the fluid in which it turned would be pushed backward. Thus the effect of screw propeller would be duplicated. Because turning the bolt pushed back the elastic substance in which it was submerged as well as producing forward movement of the bolt, it would not advance as much per revolution as though it were working in an unyielding medium; for instance, while the pitch was one inch, and theoretically considered, the bolt or screw

should move forward a distance corresponding to the pitch; because of the reaction, the degree of movement which actually takes place would be considerably reduced.

For considerations of balance, an aerial propeller is not based on the design of a single thread screw but on a double, triple or quadruple thread type, depending on the number of blades. The two blade type is the most popular though three and four blade aerial screws are employed with geared engines when propeller speed is relatively low and great thrust is required within limited effective diameter.

When Screw Works in Air.—In the case of a screw working in air, however, we are concerned with very different conditions from those found in a rigid combination such as we have just instanced. Air is a highly rarefied medium, the density being only one eight-hundredth that of water, and one six-thousandth that of steel. A *perfect fluid* is one whose *molecules* are perfectly free to move over one another with the slightest disturbing force—and air approaches very near to such an ideal fluid. With a screw working in such an elastic and accommodating medium it will not be surprising to find a certain amount of air slip beneath the blades so that the space covered per revolution is always something less than that represented by the geometric proportions of the screw blade. (See Fig. 209 B.) The axial space covered by a propeller for the incoming air is given an added velocity in passing through the propeller disc. At zero slip no aditional velocity and no rearward momentum is imparted to the incoming air stream, and as a consequence the thrust will be zero and there will be no true wake stream beyond that due to skin friction. The advance per revolution at which no thrust is obtained is termed the *mean experimental pitch* or *zero thrust pitch* of the propeller. It is a value found experimentally by artificially driving the screw through the air at increasing velocities till the point is reached at which there is no thrust. The experiment is usually done on a large whirling arm or in a wind tunnel, but an approximate value can be found quite easily by placing the estimated no-lift line on the blade section at two-thirds full diameter, this being at, or near, the center of pressure of the blade. Its value will vary slightly along the blade, but a very good approximation to the experimental value may be found by taking the section thus defined as a criterion.

Mathematical Consideration of Propeller Pitch.—The geometrical blade pitch face is the aerial span of one twist of a helical line of constant angularity and radius: each revolution is termed its *mean-effective pitch.* It is a function of the thrust of any instant and varies with each maneuver of the pilot. Thus, under climbing conditions, the effective pitch may drop 50 per cent of its value in level flight, the slip, of course, increasing at the same rate. An analogous case may be found in the slip of an ordinary bolt and nut, as often happens in driving against a heavy load. In the case of the air screw, however, the thrust is obtained *by reason of* the slip of air under the blades, so, equal to that at the section taken. The fact that only a small fraction of a complete twist actually exists in the aerial propeller does not affect the argument as the pitch is quite independent of the blade width, but is a function only of the angle and radius of rotation. It usually varies along the blade and in most cases gets greater towards the boss, so

that the blade face is not part of a true helix. It is necessary, then, to state precisely the section at which measurement is to be made. The general rule is to take the blade angle at two-thirds full propeller diameter as a basis for calculation. The value so found is the *blade pitch*, or simply the pitch, as ordinarily referred to by propeller makers and dealers, and it is the figure stamped on the boss. It is very important to remember that this is a purely geometrical quantity, depending only on the angles and proportions of the blade, and is not connected in any precise way with the effective pitch or mean experimental pitch.

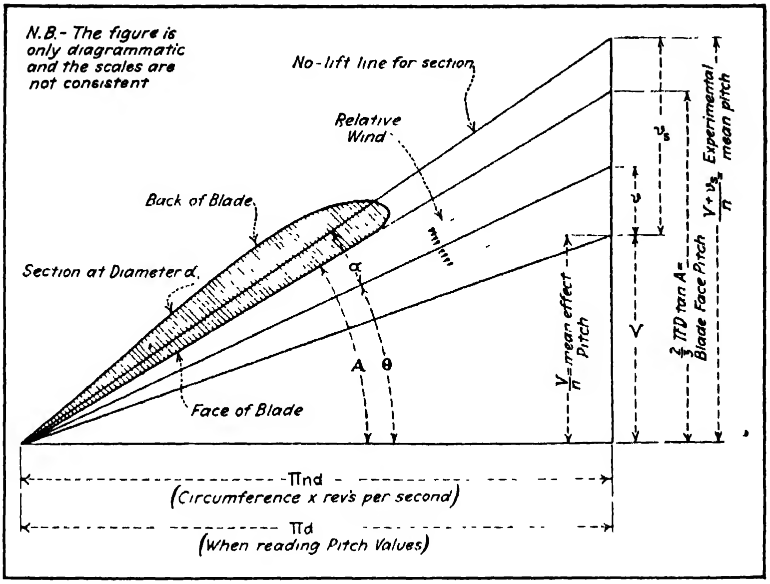


Fig. 210.—Diagram Showing Some Points of Aerial Screw Design Considered Mathematically.

The following is a key to the symbols used in the illustration, Fig. 210:

V = translational velocity (ft. per sec.).
v_1 = inflow velocity forward of blades.
v_2 = additional velocity rearwards.
v_s = slip velocity.
D = full diameter of prop.
d = diameter at any section.
n = number of revolutions per second.
α = angle of attack between no-lift line and direction of relative wind.
θ = helix angle of relative incoming air.
A = blade—face angle at any section.

P_e = mean-effective pitch $= \frac{V}{n}$.

P_o = experimental mean pitch or zero thrust pitch.
P_f = blade face pitch = 2/3 D tan A.

Propellers are made in two-, three- and four-blade types, the former being the most popular. In order to hold down or utilize the full power of a large engine, it is sometimes necessary to use a three- or four-blade type because a two-blade form, suitable to absorb the power, would need excessive pitch or diameter. A two-blade is the most desirable as it is the easiest to build and balance and the most efficient at high rotative speeds.

Theories of Screw Propeller Action.—The many theories regarding the principles which govern propeller action may be grouped in either of two classes. To the first may be assigned those which consider the action of the screw upon the medium in which it is submerged, and from the movement of the elastic medium deduce the reaction upon the propeller. To the second class belong the theories which consider only the action of the medium upon the propeller.

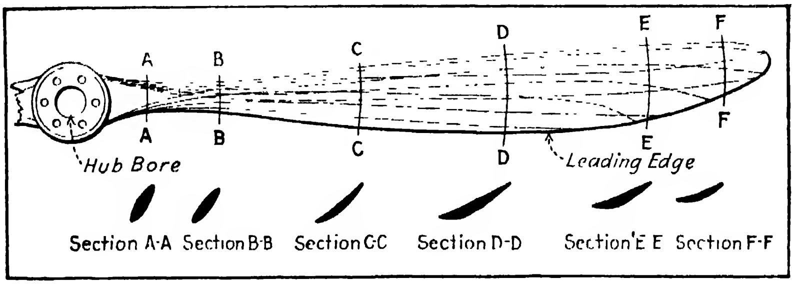


Fig. 211.—How Propeller Blade is Shaped at Various Stations Along Blade. Note Aerofoil Section at Different Points and Lessened Angle of Incidence as the Tip is Approached.

The "disc" theory is a notable example of the first class, and considers that the propeller displaces a quantity of the medium in which it turns equal to the propeller diameter, and that given a definite amount of fluid having a certain change of velocity impressed upon it, the reaction resulting can apparently be calculated at once from the known density of the fluid. This method would possess a beautiful simplicity if we knew the exact effect of a propeller upon the fluid it passes through, and if the propeller blades were frictionless. Some authorities have assumed that a screw propeller gave to a column of fluid having a sectional area equal to the disc swept by the propeller a sternward velocity corresponding to the slip, but it would appear that in theories of the first class a change of pressure of the medium in motion is of just as much importance as a mere consideration of change of velocity of the fluid acted upon.

The Blade Theory.—In the "blade" theory, typical of the second class, the face of the propeller blade is treated as if it were made up of a number of small inclined planes advancing through the fluid, and it is this hypothesis that most authorities seem to favor. As will be obvious, if the blade surface were treated as an inclined plane, the medium could be considered as imposing a thrust upon the surface which would vary with the density of the medium and the angle of inclination of the plane as the blade moved through it. Despite the variance of theories it is evident they all bring out the same fact, and that is, that rotation of a screw in a suitable medium will produce movement of

both screw and fluid in which it is submerged. If the screw is held so that it can move only in a rotary direction the column of fluid it sets in motion will only move. If the screw is operating in an immovable medium, the screw will move in a direction parallel to its longitudinal axis. If both screw and fluid are free to move, the degree of movement will depend upon the "slip" between the screw and the medium in which it works.

Propeller Definitions.—Before considering the constructional features of propellers used for the propulsion of aerial craft, it will be well to give some brief definitions. A right-hand propeller is one that when viewed from the rear, turns with the hands of a watch when driving the machine to which it is fitted ahead. Under similar circumstances a left-hand propeller turns against the hands of a watch to produce forward movement. If a right-hand propeller is turned toward the left, the effect will be to produce a reverse movement of the object to which it is applied. The "face" of a blade is the practically straight back surface, that which drives the fluid back while the screw is going ahead. The "back" of the blade is the side opposite the face, and care must be taken to avoid confusion of terms, from the fact that the "face" of a blade is aft and the "back" forward. The back of the blade is usually a cambered surface, as shown at Fig. 211.

"The leading edge" of a blade is the edge which cuts the fluid first when the screw is turning ahead, while the "following edge" is opposite the leading edge. The "leading edge" is usually curved more than the "following edge." The "diameter" of a screw is the diameter of the circle described by the tips of the blades. In symmetrical two- and four-bladed screws it is simply the distance from the "tip" or outermost part of one blade to that of the opposite member. The "pitch" at a given point of the face is the distance from the axis of the shaft which an elementary area of the face at the point, if attached by a rigid radius to the axis, would move during one revolution, if working in a solid fixed nut or non-resilient medium. The pitch may be different at every point of the face. If it is the same at all points we say that the pitch is "uniform." If the pitch is greater along the following than the leading edge, it is said that the pitch "increases axially," and if it grows greater as we leave the center we say the pitch "increases radially."

The "area" or "developed area" of a blade is the surface of its face, and the "blade area" of a screw, sometimes called its "helicoidal area," is the amount of face surface of all its blades. The "disc area" of a propeller is the area of a circle described by the tips of its blades. The "boss" of a screw is the cylindrical center to which the blades are attached, and the "hub" is the metal clamp by which it is attached to the revolving driving shaft. When a propeller is working with "slip" it advances during each revolution a distance less than the pitch, the difference between its actual advance and the pitch indicates the amount of slip. The "speed" of the screw is the distance it would advance in a unit of time, supposing it to be working in a solid nut. This is obviously equal to the pitch of the screw multiplied by the number of revolutions per unit of time.

The empirical rule that is followed usually in designing either wood or metal propellers having two blades for use in air is as follows: The diameter should be as large as possible compatible with the limits of design;

the blade area should be from 10 to 15 per cent that of the area swept; the pitch should be approximately four-fifths the diameter, and the speed of rotation should be low, not more than 1,800 revolutions per minute. As the speed of rotation is increased, the diameter must be reduced. Maximum thrust effort will be obtained with large diameter and low speed. Heretofore, when the speeds of the propeller and of the airplane were both relatively low, reasonably good propeller efficiency was secured, at least 75 per cent being common. With the present trend of development, except in the case of high-speed airplanes, propeller efficiency is often poor, and sometimes considerably less than 75 per cent. This is a serious situation that can be corrected to some extent by proper propeller reduction gears; it is probable that variable-speed gears for propeller drive will be used in the future, particularly with supercharged engines, though this will introduce undesirable weight and mechanical complications. Metal propellers of small diameter have been run at speeds ranging from 3,000 to 3,500 revolutions per minute on high-speed direct drive engines of the Bristol Cherub type.

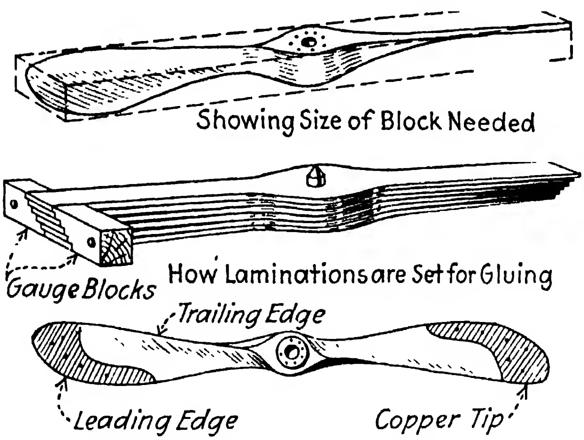


Fig. 212.—How Laminations are Glued Together to Make Block from which Propeller is Formed.

Wood Propeller Manufacturing Practice.—Airplane propellers were usually made of wood because this material is the one that has the greatest strength in proportion to its weight and has been found to be the best adapted because it is easily worked. Commonly used woods in American manufacturing practice are Honduras mahogany, birch and white oak. Spruce, maple, cherry, ash and poplar are sometimes used. English practice favors mahogany and black walnut, their preference seeming to be for the latter. Spruce is used for the manufacture of propellers for small engines to some extent. This wood has the advantages of being light and strong, as well as easy to glue, and climatic conditions do not affect it unduly. This wood is seldom used in propellers for engines of more than 60

horsepower. Propellers to absorb 100 horsepower have been successfully made with alternate laminations of maple and spruce, with the layers so arranged that the hard wood comes on the outside to better resist the compressive effect of the metal hub plates and flange.

Mahogany is comparatively light and is not difficult to glue. It is a soft wood, however, and easily marred. Quarter-sawed white oak has a high tensile strength, but unless absolutely dry stock is used some trouble will be encountered with the glued joints. The reason the quarter-sawed is used in preference to the plain oak is that the latter is apt to develop season cracks. In propellers for engines of 200 horsepower or more, birch has been

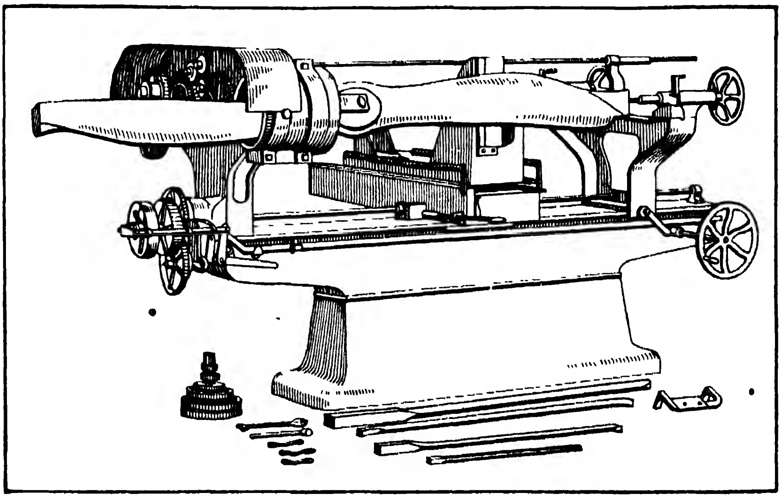


Fig. 213.—Special Lathe for Turning out Propellers.

used very successfully because it is tough and strong in resisting tensile strain and is not unduly heavy. Its disadvantages are that it is affected easily by changes of weather and will warp or check, especially when thin sections are used. For extreme climatic conditions, such as encountered on the Mexican border, mahogany or poplar has given good satisfaction. Ash is not recommended if mahogany or walnut is obtainable, because it is difficult to laminate it or work it on account of its tendency to splinter. Quartered white oak is an excellent material for use in connection with propellers for large engines.

Propeller Made of Laminations.—Any airplane propeller, except the very small ones used for operating fuel feed pumps, electric dynamos for radio, etc., is made up of a number of laminations. In the early days, airplane propellers were made from a solid piece of timber, but this practice was discontinued on account of the difficulty in keeping these in condition. A laminated propeller will not warp or draw out of shape as quickly as a one-piece propeller will. Each lamination is balanced separately, and as the block from which the propeller is to be shaped is built up in the press it is customary to lay the heavy end of one ply alongside the light end of the next layer and in this way a fairly well-balanced propeller blank is obtained.

There are two methods of gluing up the laminations. Straight material may be glued into a rectangular block and roughly band-sawed out to shape, or it may be made of laminations that have been sawed, rough bored and aligned for pitch by means of templets as shown at Fig. 212. The best care is taken in the gluing process, and good hide glue to which various chemicals are added for water-proofing purposes is used. Needless to say, the wood must be absolutely dry before gluing, and the laminations must be firmly clamped together in a powerful press while the glue is setting.

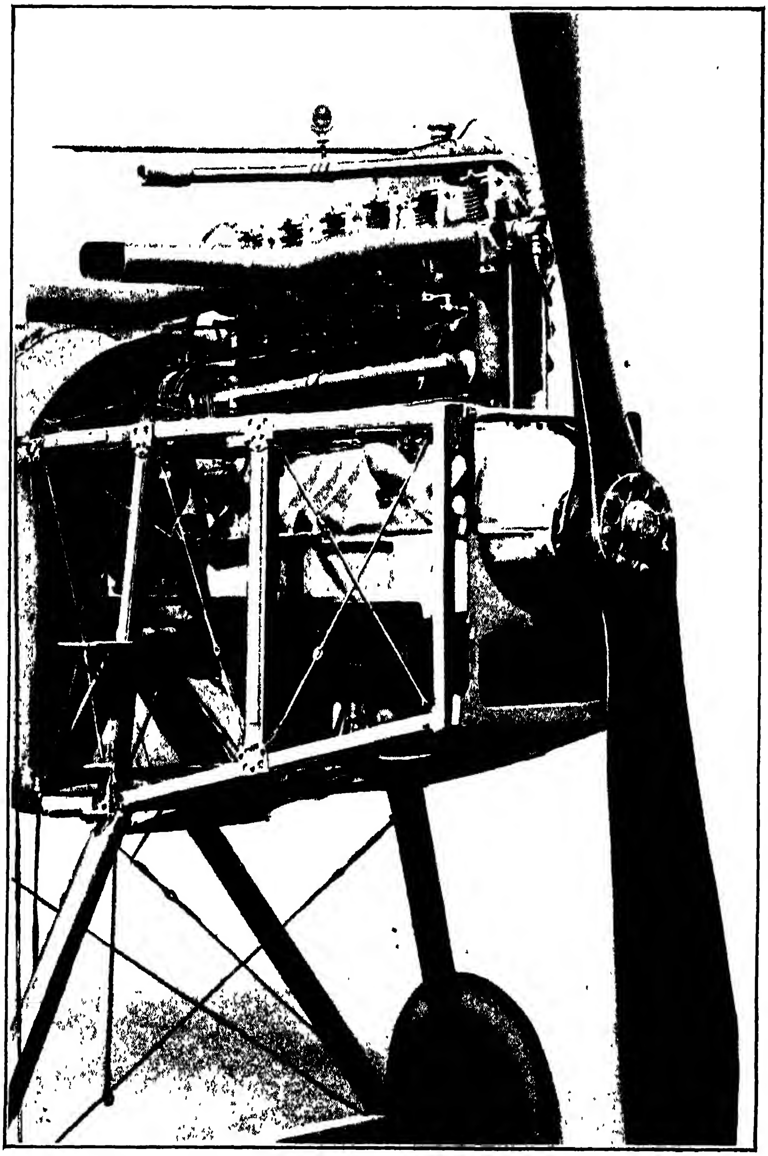


Fig. 214.—Installation of Direct Driven Tractor Screw which Turns at Engine Speed.

Shaping the Blades.—There are various methods of shaping the propeller blades, and a number of ingenious machines have been developed to do this work. The machine commonly used is a duplicating lathe, as shown at Fig. 213, which is a modified form of axe-handle machine. A model propeller is used over which the cam that regulates the travel of the cutters operates, and this shapes out the propeller to nearly its finished dimensions. After this roughing out process, the propellers are hung along a wall or stored in special rooms for a few weeks so that the wood may adjust itself to its new shape and take a final set. The finishing is done by bench workers who work the blades to size with draw knives, spoke shavers, small planes, wood rasps and hand scrapers, checking their work frequently with templates.

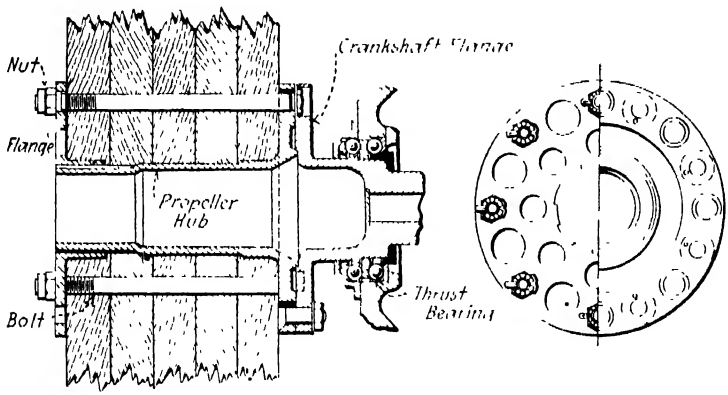


Fig. 215.—Propeller Hub of German Design is of Light but Strong Construction.

After the propeller is finished, it is carefully sand-papered and polished, the bore is reamed to fit the hub and the finished propeller is tested for balance and alignment. A high-grade piano finish is put on in the finishing department, where a coat of wood filler is applied and well rubbed down, this being followed by the application of three coats of water-proof spar varnish. Some propellers are tipped with sheet metal, which tips are securely riveted into place in order to strengthen the thin propeller blade at the point, and also to reduce the danger of splitting. Sometimes propeller blades are covered with a layer of airplane linen, which is stretched tightly over the tips and given three or four coats of "dope," which shrinks it tightly and makes it stick to the blade. The balance of a propeller should always be checked after tipping.

How Propellers are Balanced.—A propeller is balanced by the simple fixture comprising a stand, as at Fig. 216 A and Fig. 217, having a pair of straight edges which support the mandrel and which are carried high enough to allow the propeller to rotate clear of the floor. The supports should be adjustable so they can be accurately leveled. A propeller should balance in any position in which it is placed, i.e., it should not rock back and forth or move when it has been placed in any position. Endeavor is always made to balance propellers in a room free from air currents. Each blade

should be balanced in vertical, horizontal and 45 degrees each side of the vertical position. The entire propeller should be rotated so that each blade will receive both top and bottom position. If a propeller does not balance, it is usually because there is more wood on one side than on the other. Copper-tipped propellers are easily balanced by peening in the soft metal, filling the depression with solder and scraping off the surplus metal until the proper degree of balance is obtained. Untipped propellers are balanced by removing the surplus material. This is always done by taking wood

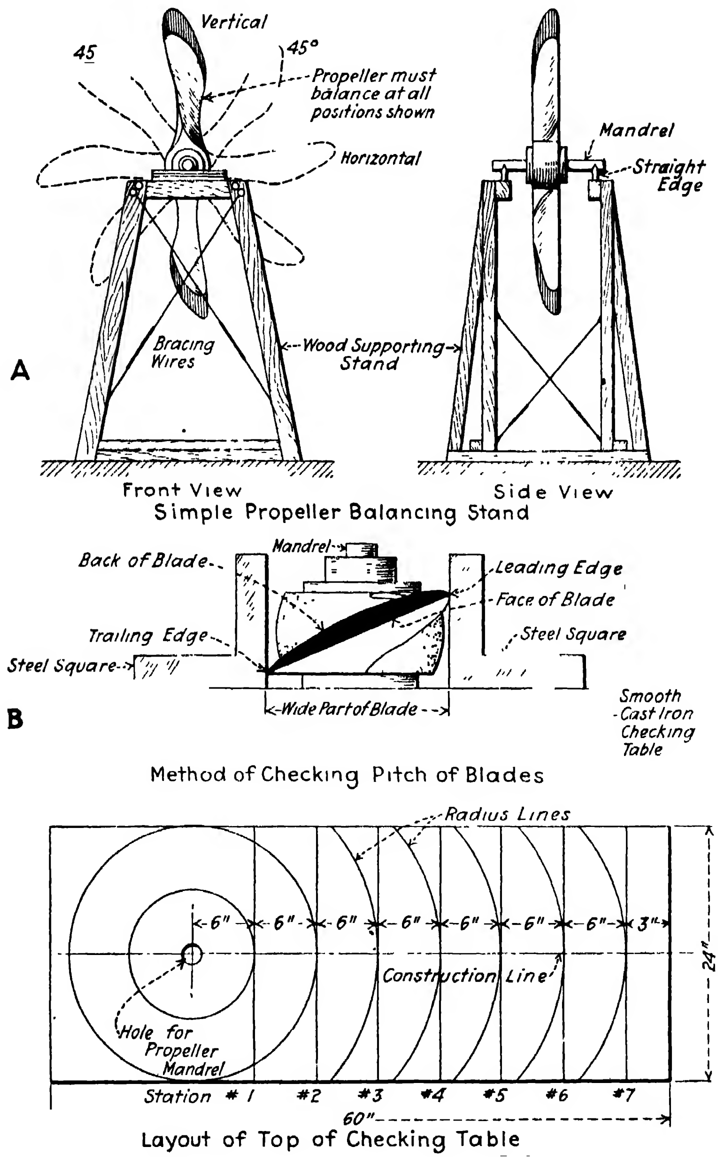


Fig. 216.—How Propellers are Tested for Balance and Blades Checked for Pitch at Various Stations.

from the back of the blade, and extreme care is necessary not to destroy the contour of the section. Sometimes, small plugs of metal are used in the hub to afford balance.

Propeller Storage and Maintenance.—After the propeller is balanced, it is stored away, in a special room where the atmospheric conditions as regards humidity are carefully regulated, until needed. Before being used, it is customary to check the pitch of each blade to make sure that it is the same at similar stations. A station is merely a point on the blade at intervals of six inches from the hub center. The blades are checked with a bevel protractor which gives the angle, or by the use of two squares, in which case accurate measurements are taken. A cast iron surface plate, accurately planed, is used for this purpose, as it is necessary to have a true surface to make accurate comparisons possible. When a bevel protractor is used, the pitch should not vary more than a quarter of a degree. It is important that both propeller blades be the same length in order to secure a well-balanced job. As propellers are designed the pitch is not the same at each station, so in checking up the same station is chosen on each side of the blade, generally at the widest portion, and the measurements taken at that point.

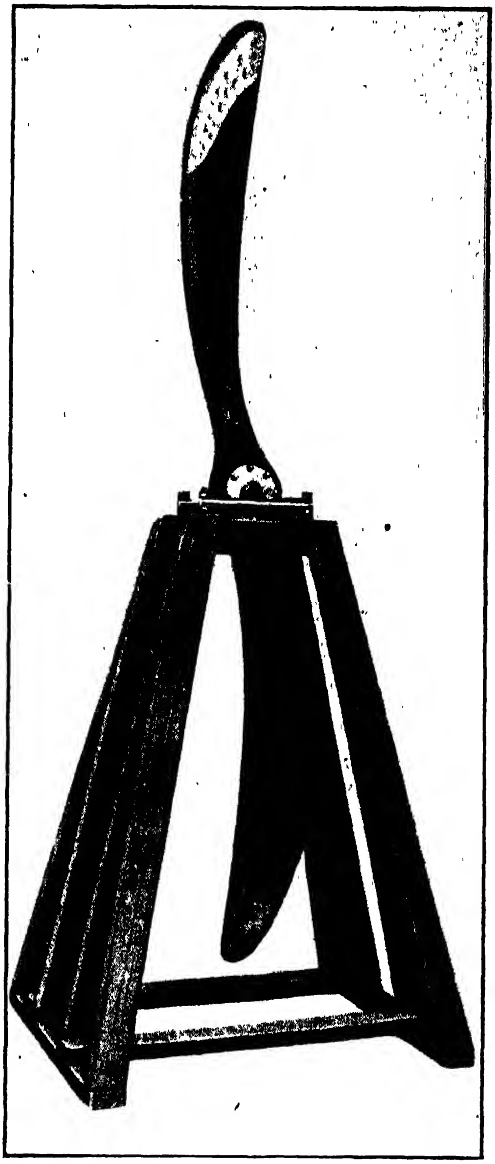


Fig. 217.—Stand for Balancing Propellers.

Propeller maintenance is an important point to consider. Propellers should be cleaned and polished with shellac and oil at the conclusion of each day's flying. The polish is composed of about six parts of shellac to one of linseed oil, which is applied to the propeller with a cloth and vigorously rubbed to a glassy finish with a piece of cheesecloth. If the machine is to stand out in the sun or weather for any length of time, the propeller should be covered with a canvas cloth or with especially

made boot to fit it. This prevents checking of the wood and warping or blistering of varnish due to the heat. As long as the finish is properly maintained, the propeller is not apt to absorb moisture. A working drawing showing a wood propeller suitable for use with Liberty engines is shown at Fig. 221 and the varying sections of the blade at different stations may be readily determined.

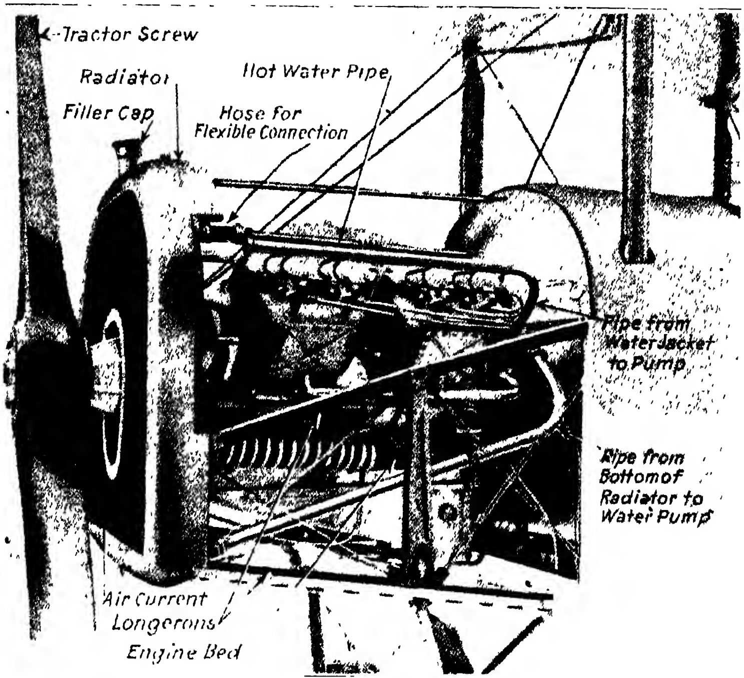


Fig. 218.—Propeller Driven at Slower Speed than Engine by Reduction Gearing.

Mounting Propellers.—In mounting propellers, great care should be taken that both blades rotate in the same plane. This is termed the "track" of the propeller and may be checked as shown in Fig. 222 A. Measure the distance from the edge of one blade to some fixed point on the plane. This measurement should be made in a line parallel with the center line of the crankshaft. Now turn the propeller through 180 degrees or one-half revolution and measure the other blade in the same manner and the same distance from the center. The variation should not exceed 1/8 inch. The propeller can be trued up as to track by shimming between the hub flange and propeller with paper or, in extreme cases, by dressing off the face of the propeller where it comes in contact with the hub flange.

The pitch of both blades should be checked with a protractor and level as shown in Fig. 222 B. Both blades should be checked at the same distance from the center of the propeller, or about two-thirds of the distance from center to tip. The difference in pitch between the two blades must not exceed 1/16 inch in nine inches. Variation in pitch can be corrected in the same manner as error in track, i.e., by shimming or by dressing off the propeller.

The fitting of the propeller hub and method of removing it are shown at Fig. 223. To take the hub off of the shaft, when the design is as shown in illustration, the first step is to remove wire lock ring from the lock nut, and screw the lock nut from the hub and then unscrew the retaining nut entirely out of the hub. Oil the threads of both liberally. Screw in the retaining nut as far as it will go, then back it out five turns. Screw in the lock nut until it touches the shoulder on the retaining nut. Continue to

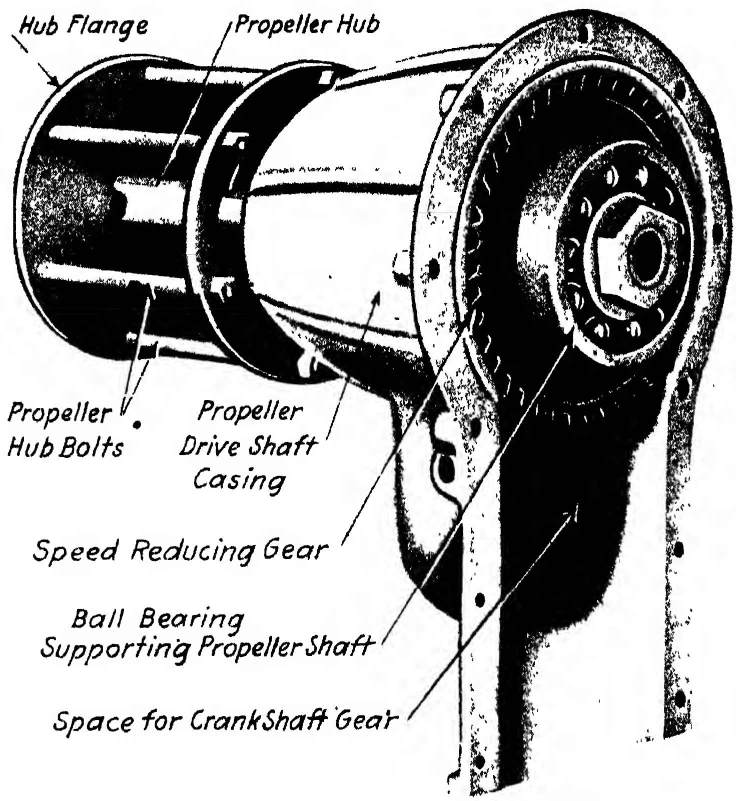


Fig. 219.—Showing Arrangement of Geared Down Propeller Drive.

screw in the lock nut, meanwhile holding the retaining nut and crankshaft stationary. This will draw the hub off the shaft. If it is necessary to heat the hub in order to start it, a blow torch should be applied to the hub barrel in the vicinity of the flange and the heat should be applied as evenly as possible.

Fitting New Hub to Shaft.—When fitting new hubs, they should be "lapped" to the shaft to secure a proper fit of the tapers. Remove the key retaining screws and the hub drive key. Use a paste of light oil and valve grinding compound. Turn the hub around on the taper, removing it frequently and cleaning off old abrasive and supplying new. When a full seating is shown, the hub should be further lapped so it will be about .001 inch tighter at the large end of the taper than at the front end. This is

done by cleaning off the large end and lubricating it with light machine oil and apply the abrasive only to the small end of the taper. Check the progress of the work by washing off the oil and abrasive occasionally and by testing the fit with Prussian blue. The final result should be reached when the color will spread thin at the large end but remain heavy at the small end of the taper.

To mount the hub, insert it in boiling water for two or three minutes to heat it and expand the bore slightly, then tap it lightly in place on the shaft after the key has been put in place and immediately apply the retaining nut and screw it tightly in place. Then apply the lock nut by screwing it into the shaft until it bears against the flange on the retaining nut. Apply the lock wire, being sure the tongue is long enough to project through both nuts. Be sure there is a clearance of at least .010 inch between the top of the key and the bottom of the keyway in the hub.

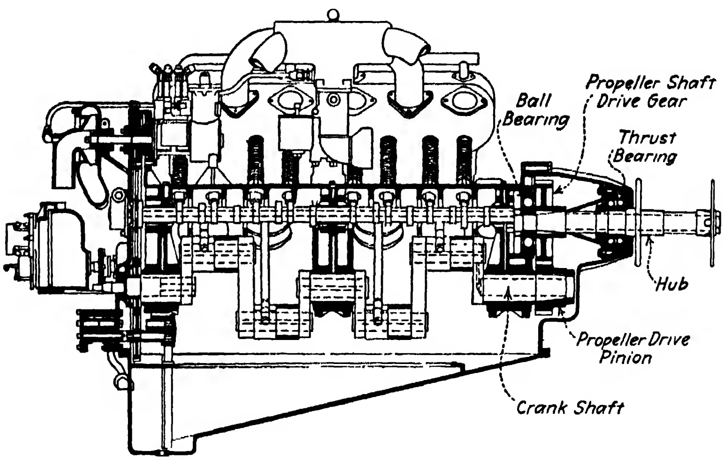


Fig. 220.—Sectional View of Airplane Engine Having Reduction Gear Drive for Propeller. Engine Runs at 2000 R. P. M. in Order to Develop Maximum Power; Aerial Screw Turns at 1500 R. P. M. for Greatest Efficiency.

Wood Propellers of Thin Laminations.—The process of wood propeller construction previously described called for relatively thick wood laminations, glued together and held in a press while the glue set. The laminations are perfectly flat and the blade contour is given by the forming or machining process after the blank is completed.

The DeGrandeville system of manufacturing wooden propellers, developed by a Frenchman of that name, differs from the conventional method of construction in the use of much thinner laminations and in the twisting of the built up laminations to approximately the pitch angle of the finished propeller and then gluing them together while clamped in this shape. The method is illustrated in Fig. 224. The view at A shows the laminations that will form the blank before they are twisted. The twisted blank in the clamps is shown at B and the appearance of the blank with

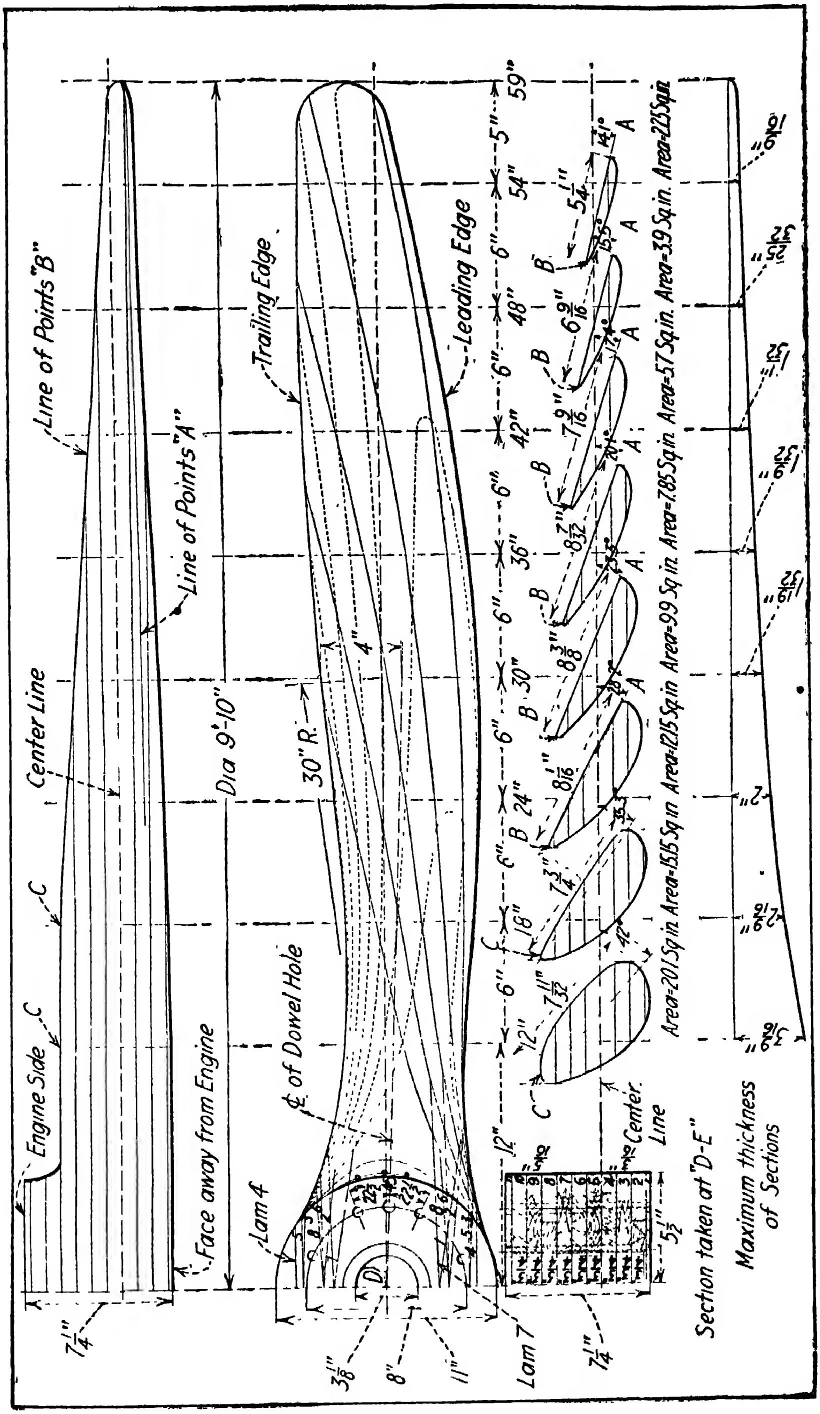


Fig. 221.—Working Drawing of Wood Propeller Suitable for Liberty Engine of 400 Horsepower, Showing Dimensions and Sections of Blade at Various Stations.

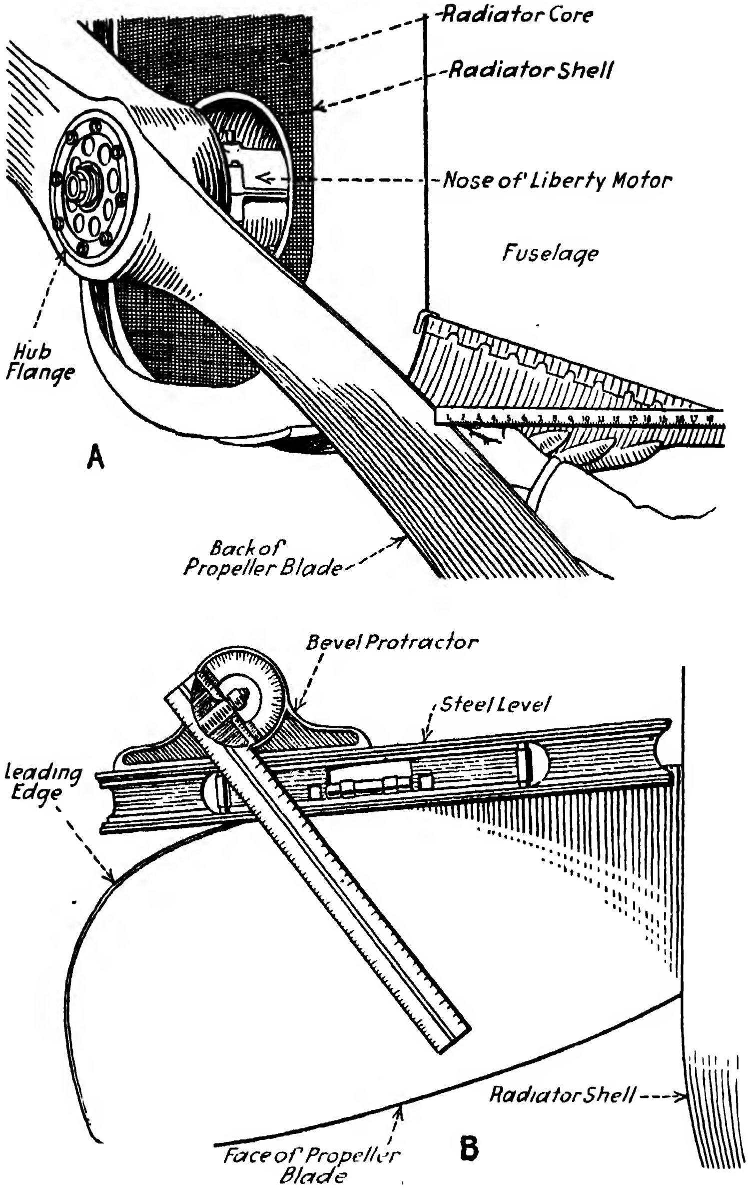


Fig. 222.—Drawing at A Shows Method of Testing Propeller for Track. Use of Bevel Protractor Depicted at B for Testing Pitch of Blades.

the upper clamp blocks removed is shown at C. The blank removed from the clamps is shown at D, the finished propeller with tips at E and without the tips at F.

Several advantages are claimed for this construction. It is said to be stronger, due to the fact that the two laminations nearest the pitch face of the propeller are practically continuous and parallel to the pitch face.

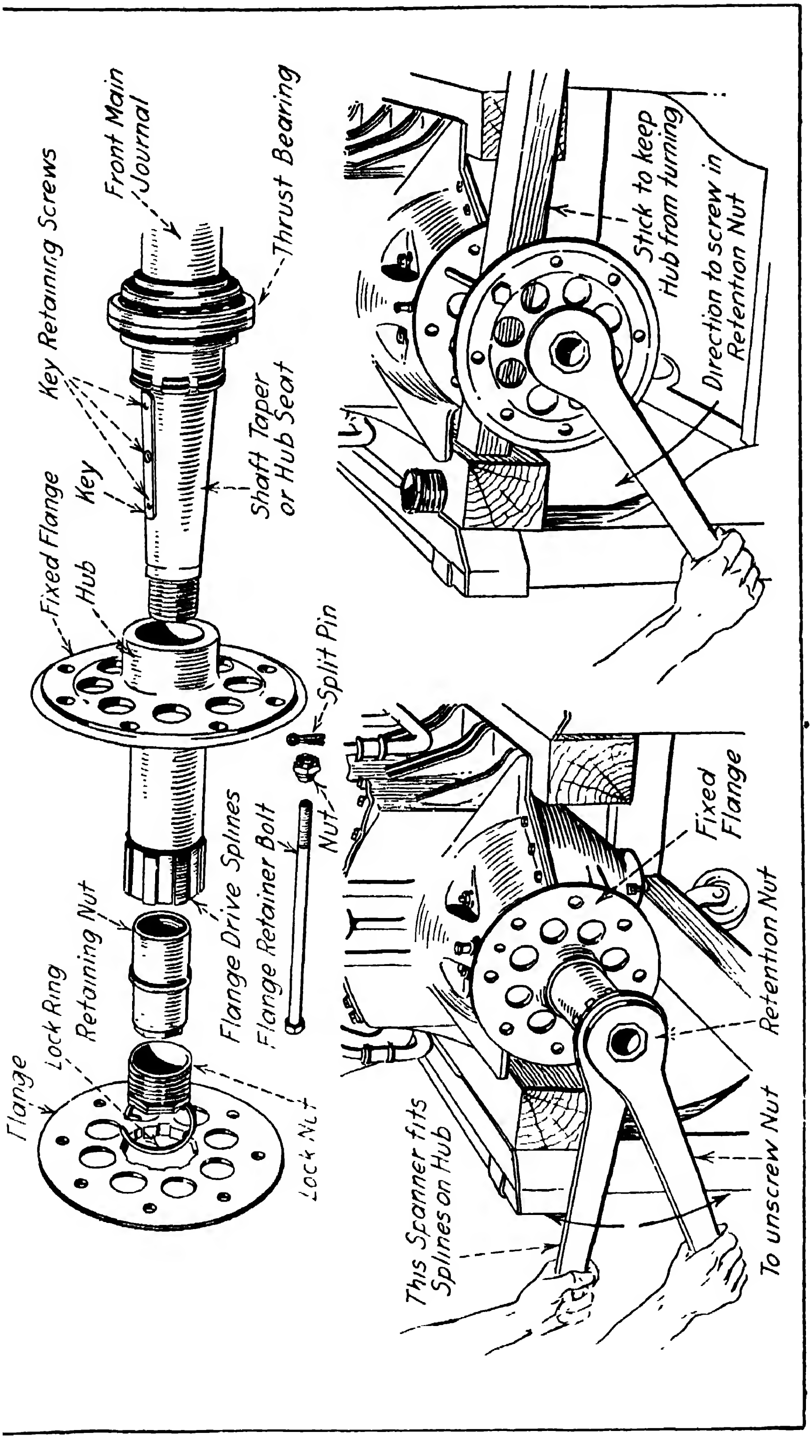


Fig. 223.—How Propeller Hub is Mounted on Crankshaft of Liberty and Similar Engines.

The usual practice is to make these two laminations of walnut, and to use some other less expensive or more easily procurable wood for the remaining laminations. It is possible to use in this system wood which would not be quite up to the standard required for the usual method of propeller manufacture. This fact alone is of a great deal of importance in view of the difficulty of obtaining perfect lumber.

The DeGrandeville system is certainly more economical of wood than the older and more usual method. There are two reasons for this. In the first place, the thinner strips of wood used for the laminations in the DeGrandeville system frequently can be obtained from pieces of timber which would not contain enough perfect wood to provide an equal quantity of material for the older system of propeller manufacture. Secondly, due to

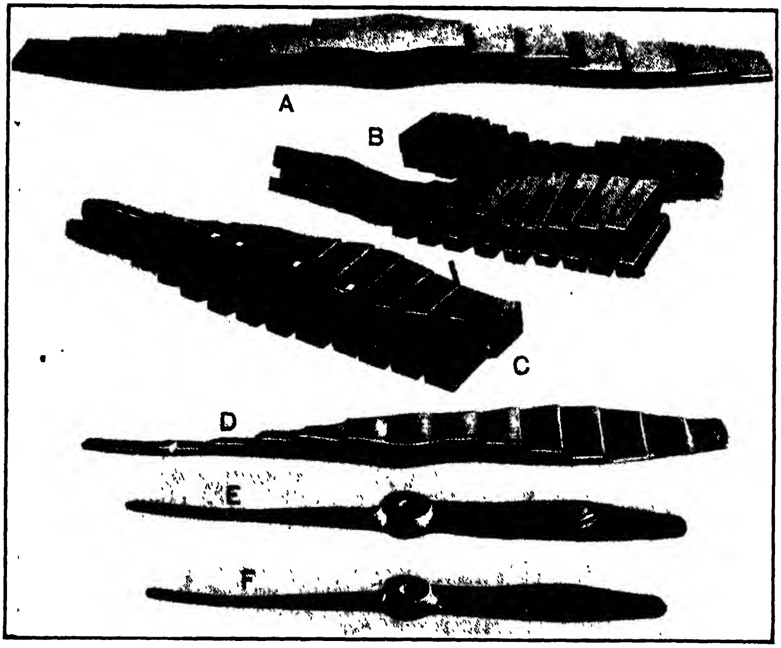


Fig. 224.—Outlining Steps in Constructing Wood Propellers by the De Grandeville System. Laminations before Bending Shown at A. B—Laminations Clamped for Bending. C—Bent Glued Blank with Clamps Partly Removed. D—Bent Blank before Shaping. E and F—Completed Propellers.

the use of a larger number of thinner laminations in the DeGrandeville system and to the fact that they are placed more nearly parallel to the pitch angle of the propeller blades, it is possible to cut the individual laminations to a shape more nearly approximating that of the finished propeller. (See Fig. 224 D.) This not only saves material, but is also a factor in reducing the time of manufacture by cutting down the amount of excess wood which must be removed in the first rough cutting process.

A thin strip or sheet of pigskin is wrapped around the end of the propeller blade, smoothed down carefully and glued in place in the usual manner. This forms a very simple method of tipping the blades, and it is

claimed that propellers tipped in this way are given adequate protection against chipping or breaking through impact with sand, gravel, water or other obstructions encountered in landing. This tipping is so simple and inexpensive that the French Government some time ago decided to tip all propeller blades in this manner for land machines as well as for flying boats and seaplanes.

Bakelite Propellers.—A composition material known as Bakelite, after its inventor, Dr. Bakeland, has been used for airplane propellers. While this substance was primarily intended for electrical purposes because of its insulating properties, it was found to possess considerable strength and it has been used for various automotive parts such as timing-gears. Bakelite is derived from the combination of carbolic acid, cresol or phenol and formalydehyde to form a resin easily affected by heat or solvents. When subjected to combined heat and pressure, the material becomes hard and is not affected by ordinary solvents or temperatures. Two methods of uti-

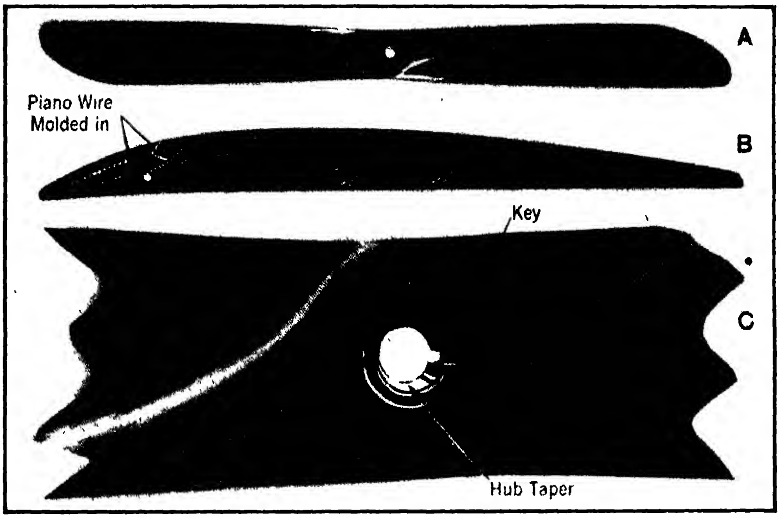


Fig. 225.—Bakelite Propeller Shown at A. B—Section of Blade Showing Bakelite Micarta Sheets of which it is Composed and Piano Wire Molded in to Strengthen Leading Edge. C—How Driving Keyway is cut Directly into the Propeller Hub which is Strong Enough to be Seated Directly on Taper Shaft.

lizing bakelite commercially are followed. In one, the material in its resinous form is combined with a filler such as wood fibre or flour and to mold it in accurately formed steel molds. The other method is to coat craft paper, cotton or duck or similar materials with the bakelite in liquid form and then pressing these sheets together to form solid blocks known as micarta. It is of micarta that propellers are made and such are impervious to moisture, which is a destructive enemy of wood. Micarta propellers are more uniform in structure than wood and almost as strong as wood propellers. Bakelite-micarta, when properly formed and hardened by combined heat and pressure is harder, stronger and more glass-like than any other material of organic origin. It is stated that micarta is heavier than

wood but that this is offset to some extent by the fact that the material is sufficiently resistant so it does not need a metal hub as wood propellers do and can be mounted directly on the engine shaft.

Perhaps one of the strongest points in favor of micarta as a propeller material is the fact that propellers can be built much more quickly by this method than by making wood propellers in the usual way. Moreover, all of the micarta propellers, as shown at Fig. 225 A made from the same mold will be exact duplicates of one another and will be practically finished when they leave the molds, requiring only balancing and slight tuning up before they can be put into service. From a production standpoint, therefore, micarta propellers are much to be preferred to wood propellers made in

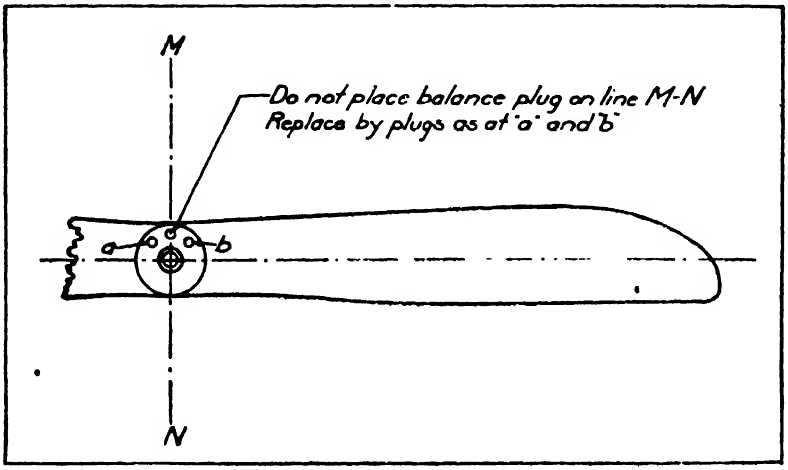


Fig. 226.—Proper and Improper Locations of Balancing Plugs in Bakelite Propellers.

the usual way, provided that the two types are equal in other respects. By incorporating wire reinforcements in the leading edge of a micarta propeller as shown at Fig. 225 B the virtual center of gravity may be moved forward slightly, which, of course, is not possible with a propeller made of wood or other homogeneous material. By locating the center of gravity slightly nearer the leading edge than the center of pressure, it is possible to provide a self-adjusting pitch feature, due to the elasticity of the micarta construction. The effect of locating the center of gravity forward of the center of pressure is to cause the propeller blade to flatten out slightly under heavy load, and thus decrease the pitch to a certain extent when climbing, while the pitch will automatically increase again under lighter load.

How Bakelite Propellers Are Made.—The most satisfactory method of making micarta propellers has been found to be to press together tightly five or six sheets of cloth or paper impregnated with bakelite, forming a board. The boards thus formed are then sawed out in the shape of propeller laminations in exactly the same way that the laminations of wood propellers are cut out. About 175 such laminations are used in the manufacture of a

propeller 4 inches deep at the hub. These laminations are laid in the mold and the plunger of the mold is inserted and brought down to press the material into the final shape of the propeller. For this work a large press with a capacity of about 1,000 tons is required. While the material is in the press, it is heated by means of steam coils to a temperature of about 350 degrees fahrenheit and the combination of pressure and heat first cements and then congeals the bakelized material into a solid mass. This process requires from 3 to 4 hours.

It should be mentioned that the forms or molds are machined very accurately, so that the plunger just fits into the main body of the mold and when the plunger goes down to the bottom of its stroke, the hole in the mold is of the exact shape and size of the finished propeller. A propeller made in this manner will have a smooth, highly polished surface, depending, of course, on the finish of the interior of the mold. After removal from the mold, the propeller must be bored true and key-slotted at the hub hole as shown at Fig. 225 C and balanced, and is then ready for installation on the plane. A second method of laminating consists in twisting the layers in a manner similar to the DeGrandeville system of building wood propellers.

Micarta propellers are balanced in practically the same way as wooden propellers. In inserting balancing plugs however, it is important that they be located properly as there are one or two locations which would weaken the hub of the propeller considerably and might cause failure. Fig. 226 shows the proper method of inserting balancing plugs in the propeller in case a plug is required in a line perpendicular to the longitudinal axis of the propeller. In such a case, instead of inserting one plug at the point required, two small plugs should be used, one on either side of the perpendicular axis represented by the line MN. The smaller plugs must, of course, be at equal distances from the line MN, representing the center line of the larger balancing plug.

A propeller was made with reinforcing wires in the leading edges for testing at McCook Field as shown in Fig. 225 B. This propeller was keyed direct to the shaft without a metal hub and was run 10 hours at 1,800 r.p.m. and then speeded up to 2,350 r.p.m. without showing any signs of failure. This propeller was designed for 90 horsepower, but at the maximum speed absorbed slightly over 800 horsepower without showing any defect. The weight of this propeller is about 39 pounds, as compared to 29 pounds for the Curtiss mahogany propeller and hub of corresponding design, and 35 pounds for the Paragon oak propeller and hub.

Tests of Bakelite Propellers.—Numerous propellers were made of bakelite and used in both whirling machine and flight tests, and the results of such tests as given in a report of the Propeller Section of McCook Field seem to be in favor of the micarta construction.

As a result of the various tests run with different types of micarta propellers, it is apparent that a duck micarta construction reinforced with piano wire imbedded in the leading edge is the best type for airplane use. Moreover, micarta propellers when properly made show a number of advantages over wood propellers as follows:

(1) Uniformity of texture.
(2) Strength.
(3) Proof against abrasion.
(4) Proof against moisture, including oil.
(5) Absence of warping.
(6) Freedom from checking and splitting.
(7) Elasticity.
(8) Adjustible pitch feature, resulting partly from elasticity.
(9) Absence of metal hub.
(10) Ease and rapidity of manufacture in quantities, once the molds are made.
(11) Uniformity of all propellers made from the same molds.

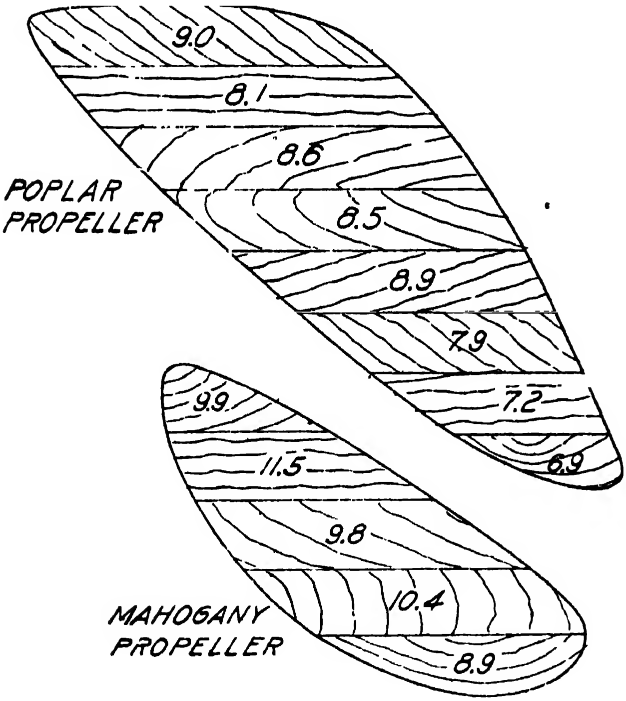


Fig. 227.—Diagrams Showing Percentage of Moisture Content in Laminations of Two Standard Wood Propellers Selected at Random.

There are, on the other hand, some slight disadvantages to the use of micarta propellers. These are principally the greater weight, the necessity for using a larger hub key when the steel hub is dispensed with, and the fact that one to two months are required to bring through any slight change in design.

Difficulties with Wood Propellers.—Probably the principal objection to the use of wood for airplane propellers is warping, and the consequent

changing of shape, due to unequal absorption of moisture in the different laminations or to inequalities in the rate of drying. It is practically impossible in the commercial manufacture of wood propellers to get all of the laminations of exactly the same moisture content. This is well illustrated in Fig. 227, which gives the percentage of moisture content in different laminations in two sample propellers, picked at random and examined. In addition to the variations in the amount of moisture content, the various laminations are rarely, if ever, of the same density. It follows, therefore, that the rate of moisture absorption of the different laminations will vary considerably with resultant warping and changing of shape of the propeller as a whole. This is particularly true in cold weather on account of the wide differences in temperature and humidity between the cold outdoor air and the air in heated buildings.

Varnish coatings, no matter how carefully applied, do not prevent wood propellers from absorbing or giving up a certain amount of moisture with changes in atmosphere conditions. This has been proven in numerous tests. Other methods have been tried of protecting the wood from moisture absorption, such as coating the whole propeller with metal-leaf applied over a sizing coat in the same manner that gold-leaf signs are applied to store windows. Electroplating and the application of hard rubber coatings also have been tried, but none of these processes has proven satisfactory. All of these methods add considerable weight to the propeller, and, moreover, are subject to chipping or breaking under comparatively slight abrasion, with the result that moisture gets in at one point and soon disintegrates the whole protective coating.

Wood Propeller Tip Protection.—In support of the practice of tipping the propeller before applying the moisture protection coating, it may be said that the chief value of the aluminum-leaf coating process is in protecting the propeller against changes in moisture content while in storage or in transit. When the propeller is once put into service, any ordinary moisture protection coat will soon become chipped or otherwise damaged through abrasion, so that it loses its effectiveness to a certain extent. So long as the aluminum-leaf or other moisture protection is not completely destroyed, however, it will continue to afford the propeller a certain amount of protection against moisture absorption and consequent warping. Moreover, the period of active service of the average propeller usually is small compared to the length of time it is in storage, so that any process which protects the propeller against moisture absorption while in storage is of considerable value even though the coating may be damaged and lose its effectiveness after the propeller is put into service, where it is subject to more or less abrasion.

Propeller tips of copper or brass are used largely on the propellers of training planes and on nearly all seaplanes and flying boats. In the latter service, the maximum protection is required against water spray, and up to the present time nothing but copper and brass approaches the desired results. In view of the fact that the seaplane propeller should be even better protected against moisture than that of the ordinary airplane, it is to be regretted that no good way of utilizing aluminum coating with the copper or brass tips has been devised.

Propellers on aviation school training planes are subjected to unusually severe exposure, due to the fact that these planes are operating on the ground, either taxiing or warming up the engines, practically one-third of the whole time the engines are running. Their propellers are therefore exposed to abrasion from various causes to a much greater extent than the propellers on service planes, which are in the air a good part of their total engine running time.

At most of the training fields an effort has been made to protect the propeller while the engine is being warmed up by placing the plane on a large platform or stand extending in front and to either side a sufficient distance to prevent small pebbles, sand, etc., being picked up by the propeller. Such protective measures are, of course, of no avail after the plane starts taxiing along the ground, but have reduced to a considerable extent the damage while the plane is stationary and the engine is being warmed up or tested.

The practice of applying special coverings to the tips of propeller blades, and particularly along the leading edges, to protect them from abrasion, water spray, etc., has been followed with varying degrees of success. A number of different materials and various methods of application have been tried for these blade tip coverings, but many difficulties have been encountered in the endeavor to develop a thoroughly satisfactory process. Up to the present time no one material or process for tipping propeller blades has proved entirely satisfactory from all standpoints. Until quite recently copper and brass tips were the only ones which gave satisfaction in service, considering only their function in protecting the propeller blades from abrasion. Linen, cotton, and pigskin tips have been developed to a point where they give good protection to the propeller against sand or small gravel, long grass, etc., and also against rain or wet grass under moderate exposure. Copper and brass propeller tips are still the only types which afford proper protection against abrasion due to gravel, tough or wet grass, flying pebbles, etc., where the exposure to these conditions is severe, as in navy planes, training ships, etc.

So far as moisture protection is concerned, the aluminum-leaf process, seems to give the best results, and it is probable that this process will be adopted as standard for all wood propellers. It is rather a difficult matter, however, to protect a propeller against abrasion as well as moisture absorption. It is, of course, physically possible to attach copper or brass tips over the aluminum-leaf coating, but the results would be unsatisfactory, owing to the numerous rivets and screws used to secure the metal tips damaging the aluminum-leaf and thus materially lessening its value as a moisture protection. Tips of linen, cotton or pigskin, on the other hand, could not be attached over the aluminum-leaf coating, as the glue used to attach them would not hold on the metal-leaf. It has been found advisable, therefore, to attach all classes of tips to the propeller blades before applying the moisture protection process, even though the latter coating may be damaged through abrasion after the propeller is put into active service.

Copper and brass tips have proved very satisfactory on the heavier types of propellers such as used on certain forms of training planes, seaplanes and flying boats, etc. They are not so satisfactory on light pro-

pellers, the blades of which are quite thin at their outer ends. It is difficult to attach a copper or brass tip to a propeller of this type without the screws or rivets pulling loose or splitting the wood in the thin sections of the blades after a short time in service. Another disadvantage encountered with brass and copper tips, especially on the light types of propellers, is cracking or splitting of the metal tips due to fluttering of the blades. The use of metal tips at the ends of propeller blades, and the necessary fastening screws and rivets impose quite a stress due to centrifugal force. The following table, computed by the Propeller Section of McCook Field shows how this augments with radius increase and weight of material.

TABLE XIX

Centrifugal Force, in Pounds, of 1 sq. in. of Sheet Copper for Various Weights, Radial Distances and Revolutions per Minute

Section radius inches	1500 r.p.m. 10 oz. Copper	1500 r.p.m. 14 oz. Copper	1600 r.p.m. 10 oz. Copper	1600 r.p.m. 14 oz. Copper
30	8.31	11.61	9.45	13.23
32	8.85	12.37	10.15	14.22
34	9.42	13.17	10.71	15.00
36	9.99	13.98	11.38	15.94
38	10.55	14.75	12.00	16.80
40	11.10	15.53	12.64	17.70
42	11.68	16.33	13.30	18.64
44	12.26	17.14	13.95	19.58
46	12.78	17.88	14.56	20.20
48	13.37	18.70	15.22	21.35
50	13.90	19.46	15.82	22.17
52	14.44	20.15	16 45	23.05
54	15 04	21.05	17.13	24.00
56	15.60	21.85	17.77	24.90
58	16 15	26 60	18 40	25.75
60	16 67	23.33	18.97	26.58

Pigskin Tips.—The application of pigskin tips to propeller blades is a comparatively simple operation. After being properly treated and scraped until very thin, the pigskin is cut to the approximate size of the tip required, coated with glue, then applied to the propeller blade and smoothed down carefully with a hardwook stick with rounded corners, or some similar tool. This is to work out wrinkles, air bubbles, etc., as the tip is rubbed into place. Wide variations have been encountered in the protective qualities of pigskin tips applied on various propellers. It is believed that these variations were due to some extent at least to the difference in the methods of scraping the pigskin before application to the blades. Some samples were used which it is believed were scraped on the outside faces instead of on the inside or part that goes next to the flesh. This is a point which undoubtedly will bear watching in the selection of pigskin for tipping propellers, as it is important to obtain the toughest and strongest material

possible for this service. In whirling tests, pigskin tips have shown up rather better than copper or brass, the pigskin evidently assisting somewhat in holding the propeller together at high speeds and retarding the development of cracks and splits occurring in blade tips.

A number of whirling tests have been made of propellers tipped with pigskin, and the results of these trials indicate that this covering when properly applied really strengthens the propeller blades and tends to hold them together at high speeds. A pigskin tipped propeller tested at McCook Field was run for 10 hours with a power input of 500 horsepower, and at the end of this test was found to be in excellent condition. The tips were tight and in place, showing no signs of failure, the only damage being a small cut in one of them, caused by some flying particle of an abrasive character. This propeller was run during the tests up to a maximum speed of 1,972 r.p.m. At this speed it absorbed a total of 553 horsepower, and after deducting the friction loss, found to be 45 horsepower at this speed, it will be seen that the propeller itself absorbed 508 horsepower net. It is believed that the pigskin tip will be found more satisfactory than the copper tip, due to the fact that the pigskin tip is not cracked by any fluttering that may occur at the tip of the blade. From practical tests run on propellers with copper tips, it has been found that the tips crack across the blades at about 10 inches from the outer ends. This seems to be due to the fact that the metal crystallizes at this point, due to the continued bending caused by the fluttering of the propeller.

Fabric Tips.—Linen and cotton due to their ease of application and the fact that they afford the propeller a reasonable amount of protection, are favored rather more than pigskin or copper. It is considered that such tips give sufficient protection to the propeller to justify using them in ordinary work. A fair proportion of propellers are destroyed in accidents of one sort or another from which not even the strongest tips could protect them. Aside from this consideration, the propellers used on army planes are seldom exposed to conditions so severe that the fabric tips would not afford sufficient protection. Taking these facts into account and also the much greater ease of application of the cotton and linen tips than other types, it would seem advisable to adopt the fabric tips as standard for all classes of service in which they are suitable. Linen and cotton tips, in addition to affording reasonable protection against abrasion, also tend to hold the outer ends of the propeller blades together at higher speeds, being fully equal to pigskin and much superior to copper and brass in this respect, because when the copper tip begins to go, and pulls loose from either screws, nails or rivets depending upon the method of fastening employed the tip of the blade is actually weaker because of the numerous holes than an untipped blade end would be.

In tipping with fabric, either cotton or linen as specified for wing covering is used. All sizing that is present in the raw fabric is removed by washing. A glue size of glue and water is used for sizing the fabric just before application. Pieces are cut from the fabric to patterns leaving an overlap over the edges of the blade. The fabric pieces are dampened with the glue size and after the propeller blade tip has been coated with a thin

coating of specification hide glue, the pieces are applied. The propeller is placed on a suitable stand, back face up; to work on it conveniently.

The fabric is then applied to the back side of the blade, beginning at the leading edge. Thorough adhesion should be secured by working with the fingers from the leading edge towards the trailing edge. Excess glue and air pockets should be removed by working from the center towards the edges, using a small hardwood stick with rounded edges. The fabric is next trimmed along the leading edge, flush with the pressure or working face of the blade. At the tip of the blade, the fabric should have an overlap of ½ inch on both faces. Allowance for this should be made in trimming. The glued fabric is smoothed over with an iron heated to about 150 degrees fahrenheit. This operation is to insure complete adhesion between the fabric and the wood, and to remove any remaining air bubbles, puckers, folds, and excess glue.

The propeller is next inverted on the stand and the covering of the pressure face proceeded with in exactly the same manner as described above. After the size has been applied to the fabric and wood the working operation shall begin at the trailing edge and proceed towards the leading edge. The fabric shall be overlapped on the back side of the blade at the tip and along the leading edge. The lap shall be about ½ inch wide. This face shall be ironed as described. Special attention shall be paid to the overlapped edges to insure their being well knit together.

Immediately following the tipping operation, the uncovered portion of the propeller should be given a coat of liquid filler. This must be worked thoroughly into the wood and allowed to become tacky, or set. It is then rubbed off across the grain. The propeller must be allowed to stand 12 hours to allow the filler to dry thoroughly. Two coats of dope are to be applied to the linen tip, allowing about 20 minutes for drying between coats. Sand lightly after the second coat of dope. That portion of the propeller which has been treated with filler, shall be given two coats of shellac, after the filler has become thoroughly dry. Each coat of shellac shall be allowed to dry at least 2 hours before applying the next coat. The entire propeller is now ready for the final finishing which consists of two coats of airplane spar varnish. The first coat should be thoroughly dry and sanded lightly with a fine grade of sandpaper before the second coat is applied.

Metal Propellers.—Various experiments have been conducted for some time both in the United States and different European countries with metal propellers, but all of these tests have not proven uniformly satisfactory. The most serious fault in a metal propeller is the fatigue or vibration effect, frequently spoken of as crystallization. Weight and rigidity are other grave defects. In order to reduce weight, hollow propellers have been tried, but these are not always practical for manufacturing reasons. Attempts also have been made to produce steel and duralumin propellers of thinner sections than wooden types, but these are not always as strong as they should be, and moreover, it was found that reducing the thickness of the section by half resulted in a gain of only about 5 per cent in efficiency. Metal propellers have many advantages, however, and recently developed types are being generally used.

A type of metal propeller that has received wide application shown at Fig. 228 is the invention of Mr. S. A. Reed, which has been developed by the Curtiss Aeroplane and Motor Company through continuous engineering study. It is claimed that this propeller has increased efficiency over a wooden propeller, that it is free from warping and that it cannot be de-

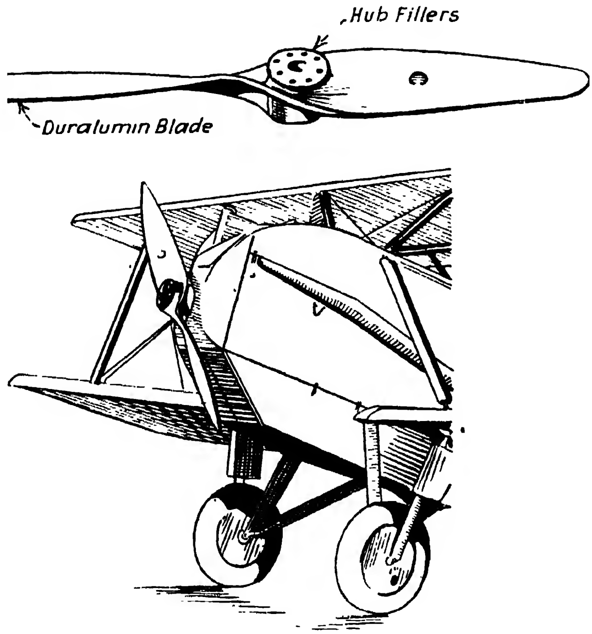


Fig. 228.—Reed-Curtiss Duralumin Propeller and its Use with Hub Made for Wooden Propeller.

stroyed by hail or rain, or abraded by high grass and that it is free from vibration. It is stated that if it is bent in a crash that it can be straightened for further use. It is made by twisting a forged slab of duralumin to secure the proper pitch and using spacer members each side of the center to form a hub that will fit the flanged hub built for wooden propellers with which it is interchangeable. A metal propeller does not require the constant attention wood propellers do.

Several failures of metal propellers in flight have been reported, these being ascribed to metal fatigue around the bolt holes, but these were early types and undoubtedly, the later forms will be materially strengthened. A metal propeller with a solid forged hub is to be preferred as it can be directly attached to the crankshaft without the use of filler pieces and hub members ordinarily required for wood propeller installation, and no breaks can develop around bolt holes, because there are none. Metal propellers will undoubtedly be used exclusively when their development is complete.

Wood propellers need periodic examination, even though this material

is one that is better for absorbing vibration than metal. Wood absorbs, metal transmits vibratory stress. Metal propellers will also require periodic inspections of points where weakness may develop, though this has been neglected somewhat because of the number in use and the relatively small number of failures. These have resulted in screws that have had considerable flying time so it may be true that fatigue must be guarded against by inspection. One propeller had 667 hours flying service, or the equivalent of 66,700 miles before it failed due to fracture across hub bolt holes.

Examination of several propellers has definitely established that they do not break all at once, but start to crack progressively, and that in the early stages these cracks cannot be detected by ordinary visual inspection methods. Therefore, there has been developed a practical process of inspection, known as etching, which can be done on the field and which will show up even the smallest cracks clearly and long before the danger point is reached. The etching process consists of bathing the central portion of the blade, where the bolt holes are located, with sodium hydroxide, and later wiping off with nitric acid. This cleans and slightly etches the blade, and shows up very clearly any cracks that may have started. Periodic inspection by this method, therefore, will assure the operator that his propeller has not started to develop fatigue failure.

Design and Construction of Metal Propellers.—The Navy Department, Bureau of Aeronautics in Technical Note No. 161 has covered the subject of metal propellers in a very thorough manner. The paper was prepared by Lieutenant-Colonel Whiston A. Bristow, a well known English authority on aviation. The following excerpts will be of interest to the student or general reader.

It may be as well to set out some of the changes that have taken place in the factors governing propeller design and construction during the past ten years. The chief appear to be as follows:

(a) The increase of top speeds from about 400 feet per second to velocities approaching, and even exceeding, the speed of sound.

(b) The difference in the maximum power absorbed per blade which has increased from 50 b.hp. to 375 b. hp. or more coincidently with a demand for higher factors of safety.

(c) The advent of the supercharged engine as a proved and practicable proposition, and consequently the necessity for a propeller of variable pitch.

(d) The demand for maximum performance either as to height or climb, or a compromise within fine limits, or the necessity for making small alterations after trial, thus involving the use of propellers with adjustable blades.

(e) Aircraft now operate in almost any weather and are often required to fly through rain or hail. This factor has exposed the extreme vulnerability of the wooden propeller in this respect.

(f) Commercial and military aircraft are now stationed for long periods in tropical countries. Climatic conditions are all against wood and glue and transport and storage considerations are greatly simplified by the provision of propellers of adjustable pitch and having detachable blades.

In view of the above it would be clearly impossible to introduce at this date propellers of wood if metal propellers were already in general use. Anyone proposing to substitute wood for steel would be regarded as a dangerous person. So great, however, is the conservatism of mankind generally, that wooden propellers continue to be specified, and the advocate of the metal propeller is often looked upon as an experimentalist to be regarded with extreme suspicion.

Metals Suitable for Aircraft Propellers.—The ideal metal for aircraft propellers should have the following characteristics:

(1) It should be a native product.
(2) Capable of being easily made to any size or section.
(3) Possess the specific gravity of magnesium and the strength of steel.

No such metal has yet been produced, and the choice of an alternative raises several important questions. Even metal propellers, as integral units, are not a practical proposition if all the changed factors are to be provided for. It follows that a consideration of metal propellers is largely confined to the question of the blades as the hubs can easily and properly be supplied by the engine makers as part of their equipment, and in the following the word (propeller) is therefore mainly used to cover the blades alone.

Metal propeller blades can be made of steel, which is produced in most countries, and alloys of aluminum which are the native products of only a few countries. The aluminum alloys are, broadly speaking, either of somewhat higher specific gravity than aluminum as, for example, Vickers Duralumin or Schneider (Creusot) Alferium, or of lower specific gravity by reason of the admixture of Magnesium, as in the German (Electron). The respective specific gravities are, Aluminum 2.6, Duralumin 2.85, Electron 1.78.

This latter metal need not, however, be seriously considered at the moment as it is affected by moisture, will almost dissolve in sea water, and is inflammable when in a finely divided state such as swarf from machining or grinding. The same remarks apply to any blades made mainly of magnesium.

Duralumin is far more suitable and has already been used, notably in the Reed propeller. It can be used for both hollow and solid blades, the latter up to a certain size, and lends itself readily to all machining operations. It has also been proved that the anodical process, or a coating of suitable varnish, renders the material immune from galvanic action and the corroding effect of the atmosphere or sea water.

A study of the foregoing for the generality of cases leads to the following conclusions; that duralumin propellers are suitable almost exclusively for very high-speed aircraft requiring propellers with a top speed equal to or exceeding the speed of sound. Such propellers are usually fitted to ungeared water-cooled engines in which the crankshaft speed has been increased to a very high figure in order to reduce the weight-horsepower ratio and for such engines duralumin propellers are technically the most suitable. The weight of such propellers is low due to their small size, and

the high speed of the aircraft and the absence of transmission losses probably almost balance the relative loss of efficiency compared with the geared propeller. For propellers of this character the solid bladed type is used exclusively, and for very good technical reasons this practice is not likely to be varied in the future. Large solid slower running duralumin propellers are however, heavier than the hollow steel type whilst large duralumin blades compare favorably as to weight, but are more difficult and expensive to make, in addition to possessing inherent disadvantages which do not exist with steel.

Propellers of steel have been made since 1917, notably the Leitner-Watts type. The blades are hollow built up in laminated form from steel sheet. At first the whole propeller was made in one piece with the hub, but for several years past the blades have been detachable, being held in a steel hub and being adjustable as to pitch. Experiences shows that the relation between the inertia of these blades and the strength of the material employed safely admits of peripheral speeds up to about 960 feet per second so that steel in this hollow laminated sheet form can be used for the great majority of propellers. It has the advantage that it is a native product in many countries, is cheap, can be easily protected against corrosion and its physical properties and manufacture are well understood by a number of firms. Tests to destruction also reveal the fact that in this built up form of steel construction, disintegration never occurs suddenly as in the case of light alloys, but is always preceded by ample warning given by the commencement of small cracks at certain places.

Leitner-Watts Steel Propellers.—This propeller is entirely of steel and consists of a separate hub, often made by the engine maker under license, into which the blades are fitted. The hub is made in two portions clamping together over a flange on the blade, which is obviously the most simple and secure method of holding the blade firmly. In addition, it has the merit of bringing the point of attachment to the shaft as close as possible. By clamping over a flange into which every lamination enters, the heavy centrifugal loads are distributed in such a manner that localized stresses are of a small order. The hubs, although they cannot possibly come adrift in operation, are capable of being unlocked in order that the blade may be adjusted at to pitch, or replaced if damaged. The figures of tests conducted by the National Physical Laboratory show that, with these propellers, if the blades be set anywhere over a range of 10 degrees about the mean setting, the new propeller resulting from such resetting will have an efficiency within 1 per cent of the possible maximum.

In the first types of these propellers the hubs were too long, resulting in a small loss of efficiency, and reducing the cooling effect over the engine crankcase. In the later types, however, this fault has been eliminated by considerably shortening the hubs. The blades are built up from sheared out sheet steel pressed to shape and welded together at the edges. Each laminated sheet in the blade is continued into the attachment flange and the inner laminations are shaped in such a manner as to bring the center of gravity of the blade as near the shaft as possible.

The building up is accomplished in such a manner that riveting is dispensed with. The welding is, roughly speaking, parallel to the radius and

is therefore not stressed to any extent and the weld at the root, where all the sheets enter the holding sleeve, is under compression. The sheets in the blade are of different length, giving the necessary taper in thickness towards the top, and the laminated form of construction increases the strength of the finished blade above that of its component sheets and, in addition, assist considerably in damping out vibration.

With this type of construction it is perfectly easy to make hubs which will take a wide range of blades, and also hubs to take 2, 3, or 4 blades, so that any type of propeller can be built up from stock units. Naturally, the balancing of all blades has to be performed with the greatest exactitude, but the limits now are fine enough to enable a damaged blade to be changed for a similar blade from store, without it being necessary to take off or re-balance the propeller, and actually this has been done in many cases. A three-bladed propeller for the Napier 1,000 horsepower Cub engine was made up from stock Condor blades and a three-way hub. It functioned perfectly and was adopted for the machine without the propeller makers knowing anything about it. The largest propellers of this type made up to the present are the two-bladed propellers for the 700 horsepower Rolls Royce Condor engine; they are 16 feet in diameter and rotate at 1,000 r.p.m., a peripheral speed of about 840 feet per second. The same type of construction is employed for top speeds up to about 940 feet per second, but for higher speeds the Leitner-Watts propellers have blades of solid duralumin fitting into the standard steel hubs.

It was only natural that the first all steel, laminated, hollow, welded propellers, with detachable and adjustable blades, should be regarded with considerable anxiety as to their weight performance and reliability. The steel propeller is heavier than the wooden, and as some of this increase of weight is in the blade it is an advantage from an engine point of view by reason of the increase in flywheel effect. The increase of weight, however, is not sufficient to adversely affect the crankshaft and end bearing, neither is the performance affected. Machines fitted with this type of propeller have in the majority of cases a better all-around performance although carrying the extra weight of the propeller and without any reduction of the military or paying load. A series of comparative tests were undertaken at the R. A. F. recently with Leitner-Watts steel propellers as against the standard wooden propeller on different types of machine and engine. In no case was the performance with the steel propeller inferior, and in most cases it was appreciably better. On the Nighthawk-Jupiter, for example, the rate of climb with the steel propeller at all speeds between 70 and 90 m.p.h. was about 200 feet per minute better, an increase of about 20 per cent. At 110 m.p.h. the metal propeller gave the machine about double the rate of climb. One point emerged very clearly from these tests and that was the consistency of the results with steel propellers, whereas with wood it was impossible to obtain check figures within anything like such narrow limits of variation. With regard to reliability, numerous engineers believed that propellers of this type would either tear out at the hub or split at the weld. For the reasons already given, however, they do neither of these things. Some of the early blades have been in service for

years without any trouble whatever, and later blades have been spun up to 200 per cent overload without breaking down. They are extensively used in the British Air Force, and samples cut up after two years service have revealed no sign of fatigue either in the original steel or the welding.

In one test a L-W metal propeller was fitted to a Liberty engine absorbing full power at about 1,600 r.p.m. When the engine was running on full throttle it was switched off and just as it was about to stop it was switched on again. This procedure was continued for ten hours at the end of which time all the engine cylinder water jackets had split open, but the propeller was undamaged. Incidentally, the test was a good testimonial to the Liberty engine which functioned perfectly in spite of being nearly wrenched off the stand each time the ignition was switched on. The jackets could not be expected to withstand such treatment especially as they were 6 years old and probably very corroded.

There is no doubt that this type of steel propeller has made good with regard to performance, reliability and durability, and nothing can be urged against its adoption under these heads. It has also the added advantage from a military point of view that ordinary aircraft machine gun ammunition has little effect upon it, and in many cases a shot-up propeller would continue to function long after a similarly shot-up wooden propeller had disintegrated.

Conclusions.—Consideration of all the evidence in respect to the requirements to be met in the design, construction and operation of propellers leads Lieutenant-Colonel Bristow to the following conclusions:

(1) That by reason of the changed conditions set out in the beginning of the paper, wood can no longer be considered as a suitable material for aircraft propellers.

(2) That steel is the most advantageous substitute from the engineering standpoint, and it also has the advantage of being a home product.

(3) That the hollow laminated steel blade can be satisfactorily constructed in such a manner that its tensile strength is sufficiently great to allow it to deal with the inertia and other forces of the great majority of propellers up to top speeds of about 960 feet per second.

(4) That for speeds beyond this there is at present no alternative to the light alloy propeller and that those of the Reed type have proved themselves efficient and able to withstand top speeds beyond the speed of sound and to absorb very high power outputs.

(5) From primary considerations and from actual experience it is considered that it will be found desirable in future in the case of duralumin propellers to make the blades detachable and the hub of steel. The more duralumin is worked the stronger it becomes; therefore, the hub and blade roots which should be the strongest are at present the weakest. This introduces variations in strength which could be mitigated by using rolled plates, the thinner the better. It must also be taken into consideration in designing the

hub that duralumin is weaker than steel, weight for weight, and it is only when the very serious centrifugal load is added that duralumin becomes the more favorable material. There is, of course, no need to make the hub specially light, as the centrifugal stresses due to its own rotation are negligible.

(6) It is impossible to make any hard and fast statement as to which type of propeller will be the lightest for a particular job. Solid duralumin is heavier, size for size, than hollow steel, viz.: 1.9 to 1.3 taking wood as 1. This is roughly approximate for propellers up to about 11 feet in diameter. Beyond this length steel becomes relatively lighter and wood and duralumin increase approximately according to the cube law in the case of solid and the square law in the case of the hollow construction. Duralumin, therefore, is heavier and lighter than steel in some sizes. In the case of the Leitner-Watts Condor steel propeller which is 18 feet in diameter this is lighter than if made in duralumin, but if the engine is run ungeared a duralumin propeller becomes possible and would be lighter.

(7) The case for metal as against wood does not rely upon performance. It is satisfactory to note, however, that in a long series of independent tests carried out both at Farnboro and McCook Field metal propellers gave the better performance.

(8) There is every indication that the military aircraft engine of the future will be provided with some type of supercharger necessitating a variable pitch propeller. This will rule out entirely any propeller of the integral type whether of wood or metal, and the ultimate propeller must have separate metal blades.

(9) Quite apart from military considerations there are the fundamental aerodynamic factors governing the changes in the speed of a propeller during the taking-off and flying periods and their important influence on the design and performance of the aircraft itself. A proper solution of the difficulties these present can only be obtained by the employment of a propeller of variable pitch, i.e., variable in flight either automatically or at the will of the pilot. Each of these two types has been designed, and in some cases tested with most encouraging results.

Screw Overlap in Multi-Engine Types.—In designing multi-engine planes especially if metal propellers are used, care must be taken so the propellers will not overlap. For example, in a tri-motor plane with one engine mounted on the fuselage and two carried outboard; one under each wing, the outboard motors should be so spaced that the disc area, or blade swept area of their screws should be clear of the slipstream resulting from the central propeller. If there is an overlap, there is an area of disturbed air in which each blade of a side propeller will move during each revolution. The air pressure will vary and consequently the variation in thrust from the undisturbed air to that of the central propeller slipstream cannot fail to produce vibratory stresses in the blades. If wood propellers are used, much

of this vibration will be absorbed by the material of which the blade is composed. If metal blades are used, the stress will be transmitted along down the blade to the point of attachment at the hub. If this is weakened by holes, there may be a very slight movement, that repeated 3,000 times per minute, will in time fatigue the stressed metal. Metal propeller failures have always taken place at the point where the greatest stress was not adequately resisted, or in the center portion.

When two engines are mounted tandem, the disc area of the rear propeller should be such that it will lie entirely within the slipstream of the front propeller. In such installations the tractor screw is sometimes of lesser pitch and greater diameter than the pusher screw, which must work in disturbed air. Overlapping is not common in twin-motored airplanes where each engine is carried outboard because the fuselage usually comes between the engines. In seaplanes, where the engines are carried above the boat hull there is also an appreciable space between the power units and the disc areas of the screws are separated by a corresponding space. The air screws of tri-motored airplanes that may appear to have an overlap when viewed from the front may have no real overlap because the front engine may be located far enough forward so its slipstream will have necked down before the side propellers can intercept it. The amount of this diminution in slipstream area may be taken as 80 per cent of the diameter at a distance of 50 per cent of the diameter or more back of the propeller. The nature of the stresses set up in the after propellers of an overlapping combination are analogous to those set up in the after propeller of a tandem combination when in the latter case a sufficiently small diameter to prevent the tips from extending outside of the slipstream is not provided. It has been stated that this point has been taken into consideration in designing the latest Ford-Stout tri-motored all metal monoplanes and that the wing supported motors are carried out far enough so there will be no contact of their blade tips with the slipstream of the central and forward screw.

Variable Pitch Propellers.—The aeroplane of today requires a considerable field area for rising and landing, and many designs can effect a landing only at high speeds, which makes the operation of landing to a certain extent more hazardous than average flying. If really reliable and easily operated variable pitch propellers were available, the landing speeds on aeroplanes could be cut at least in half. This is exemplified by tests made at McCook Field, with machines equipped with the Dicks steel variable pitch propeller. In landings with the propeller at constant pitch the machine came to a full stop in 625 feet and the same machine landed in 239 feet when the variable pitch propeller was used.

Variable pitch propellers are also of great importance in connection with high altitude flying, as the writer has previously mentioned, which is likely to become a feature of aerial transportation of the future. There, the value of the variable pitch propeller lies in the following: The engine loses power with elevation, because of the reduced content of oxygen in the volume of air inducted into the cylinders, and the resultant ability to burn less fuel. In other words, the engine at higher altitudes acts as if it were partially throttled. Superchargers precompress the air delivered into the induction

system of the engine and in this way restore the engine power delivered to the propeller. Since, however, the medium in which the propeller operates is of reduced density, the increase in speed by itself does not produce a corresponding increase in thrust, unless the propeller pitch is varied to a steeper angle to secure more of a "bite" on the thin air. Because of this the variable pitch propeller becomes a natural adjunct to the supercharged aeroplane engine. They would also be valuable in connection with airship propulsion.

The problem of designing a variable pitch propeller is quite simple at first glance, it being only necessary to provide some kind of a gear device to turn the blades about their longitudinal axis. The difficulty of the problem lies, however, in the fact that in a variable pitch propeller, the blades must be separate from the hub. At the same time, the stresses induced by centrifugal forces in the propeller are so high that it becomes extremely difficult to secure a method of connection between the propeller hub and the blades that could withstand these stresses. During the war Mr. Hart of California developed a wooden blade propeller having the variable pitch feature. This propeller was taken over by the War Department, and a great deal of experimental work and design was applied to it at McCook Field with what are said to be highly gratifying results.

Variable pitch propellers have been a feature of small motor boat design for some time and various forms have been devised that have permitted not only a variation in pitch angle of the blades but a complete reversal of their position. When the blades are set in a neutral position there is practically no thrust so such a propeller serves also as a clutch and reverse. Difficulties are experienced in the practical application of marine variable blade propellers and the problem of centrifugally produced stress on the blades is much less than it is in the larger diameter and equally high-speed aviation propellers. The operating mechanism adds weight to an airplane propeller and very careful designing is necessary to secure adequate strength, whereas marine reversing or variable propellers are not nearly as much of a problem and the design and its practical application is much more easily solved. Despite this fact, while many reversible propellers have been offered to boat men, only a few forms have survived the test of time.

The fastening of the blades to resist thrust stresses is not nearly as much of a problem in aerial screws as that of having a fastening that will be at once strong and unyielding when the blade has been adjusted, yet permit of blade movement under full load, if necessary, when it is moved by the actuating mechanism. The tendency of a revolving air screw is to throw off its blades from the hub tangentially, so the blades must be very firmly secured at the hub to resist this centrifugal force. Then again, in aerial screws, the actuating mechanism must be as simple and light as possible whereas the factors of weight and mechanical complication are not nearly so important in marine applications.

The Dicks Propeller.—The subject of variable pitch propellers for aircraft is a large and comprehensive one that is worthy of a special treatise and even a brief mathematical consideration of the many engineering problems associated with variable blade air screw design is not within the scope

of a general treatise of this character. A brief discussion of several forms that have been tried will suffice to give the reader some idea of what has been accomplished along these lines.

Of late all-metal variable pitch propellers have constituted a problem of considerable difficulty, as it was believed that structures operating under the conditions of aeroplane propellers and made up of steel would be subject to crystallization of the metal and subsequent failure. The Dicks propeller developed by Thomas A. Dicks of Pittsburgh is shown in Fig. 229

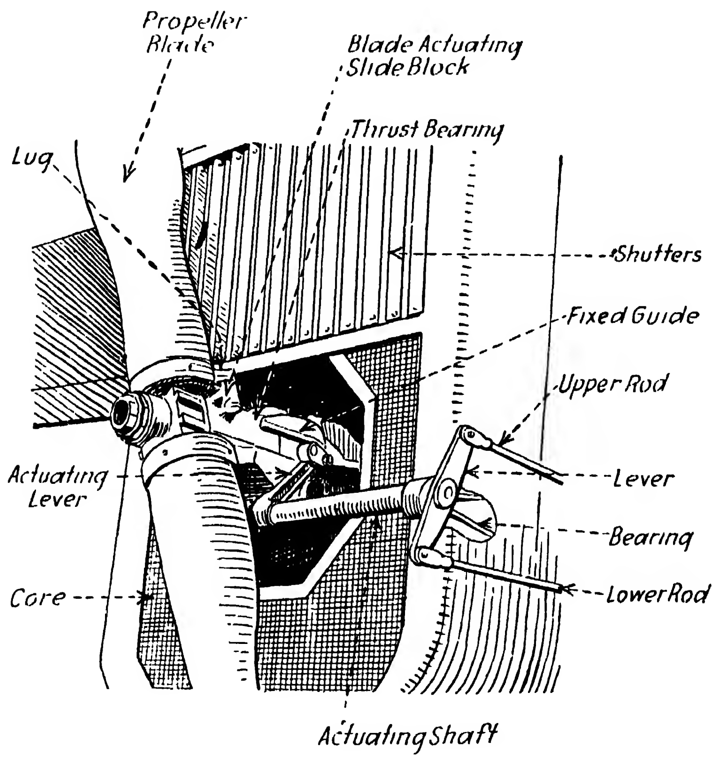


Fig. 229.—The Dicks Variable Blade Airplane Propeller and its Actuating Mechanism.

as mounted on an aeroplane at McCook Field. The blades of the Dicks propeller are machined out of a special alloy steel so as to fit over a taper mandrel. A series of specially designed reamers are used to give each section the exact dimensions. The blade is then compressed to size over a series of mandrels. The gear for turning the blades and thus varying the pitch is shown in the illustration. An interesting arrangement for holding the blades in the hub is used. In flight tests on a DH plane with Liberty motor, the same speed was developed with the variable pitch steel propeller as with the permanent pitch wooden propeller, but the ground run on landing was cut practically in half. The Dicks propeller is somewhat heavier than the standard wooden propeller, which, under certain conditions, may

prove to be a handicap by placing the center of gravity too far forward. If it should prove to be possible to use lighter alloys, such as duralumin, for the blades, instead of steel, not only the weight of the unit but the centrifugal stresses produced by the blades on the hubs and connections would be materially reduced. A special system of controls has been developed for this propeller, as well as means for regulating the carburetor throttle in conjunction with the variations of the propeller pitch.

The blades are so held as to be free to turn around the mandrels or arbors to which they are attached. A small lug at the bottom of each blade is joined to a blade actuating slide block which moves longitudinally on V ways or guides machined on the propeller hub member. One of these slide blocks is used on each side of the hub, each block being in connection with and actuating one blade. The blocks are permitted freedom only in a longitudinal direction or back and forth along the guides on the hub. The slide blocks terminate at their back ends into a member on which a ball bearing thrust collar is mounted. The outer race of the bearing is housed in a non-rotating member or housing while the inner race of the bearing is free to rotate with the propeller hub and, of course, the slide blocks it carries. The fixed housing of the thrust bearing is kept from rotating by two projecting lugs passing through slotted fixed guide members rigidly secured to the engine crankcase. This collar or housing is fastened to a shift lever by a short link, the shift lever being attached to the actuating shaft, supported at its outer end by a suitable bearing as well as at its inner end. A double arm lever is keyed or otherwise rigidly fastened to the end of the shaft and this arm may be moved by push and pull rods or cables to the operating mechanism convenient to the pilot by which the shaft is oscillated in its bearings, this producing a back and forth movement of the sliding blocks and a corresponding movement of the propeller blades around their supports. The lug attached to the bottom of each blade is free to move around on the arc of a circle only when the sliding block is moved. When the sliding blocks have been placed in the position necessary to secure the desired angle of attack of the blade, the operating mechanism is locked in position by the pilot and the propeller operates as a fixed pitch form.

Levasseur Propeller.—Another variable pitch propeller that is now seven or eight years old is shown at Fig. 230, this being the invention of a French aeronautical engineer, Pierre Levasseur. In the Levasseur variable pitch propeller, the wooden blade stub is in compression from the inside instead of being held in compression from the outside. The general view of the Levasseur propeller shows that the propeller blades are connected by anchor bolts, with castings mounted on lateral hollow shafts in the propeller hub. The pitch variation is carried out by displacement of these mountings on their respective shafts. The centrifugal forces are taken up by the ball thrust bearing shown at the base of each blade support.

Tests carried out in the laboratory of the School of Arts and Manufactures and at the Chalais-Meudon Field have shown that the new propeller gave satisfaction. The weight, was somewhat greater than of a constant pitch propeller, but a reduction is expected from an improvement in the design and material of the metal parts. A ten-hour test of the propeller

run by a motor has shown that variations of pitch could be carried out under all conditions of operation without requiring any excessive muscular effort on the part of the pilot.

The chief point of interest in this design is the care with which the problem of holding the blades firmly against centrifugal displacement has been attacked. Metal anchor pieces are imbedded in the wood laminations as shown, these being arranged in stepped relation to avoid undue weakening of the wood structure. Tension bolts of alloy steel extend from the anchor pieces through an anchor plate casting or forging which fits on a tapering section mandrel projecting from and forming part of the propeller hub. The casting projecting into the blade root or base is hollow to house the

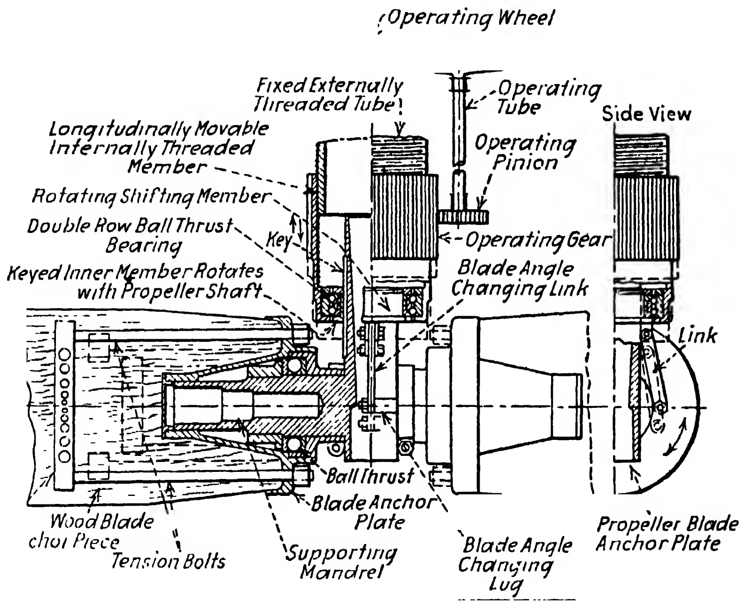


Fig. 230.—Actuating Mechanism and Construction of Propeller Blade Anchorage of Levasseur Variable Pitch Propeller.

large ball thrust bearing. This is held in place by a threaded retention member bearing against one of the races and screwed into the blade anchorage member. The blade is securely held by the tension bolts and thrust bearing from flying off at a tangent when the assembly is rotated at high speed.

The actuating member by which the blade is displaced angularly is by a sliding member and short links. The sliding member, which carries the inner race of the double row ball bearing, is keyed to and must rotate with the propeller hub. It carries lugs on its face to which the blade actuating links are attached. The method of moving the sliding piece is one that permits of very positive and sensitive control of the blade shifting links. There is an externally threaded, fixed tube attached to the motor base. An internally threaded sleeve with spur gear teeth on the exterior can be screwed back and forth on the fixed tube by turning the hand wheel, op-

erating tube and pinion attached to it. The outer race of the double row bearing is carried in the end of the internally threaded sleeve. It will be apparent that the interposition of rotating anti-friction members will permit the propeller hub to be rotated by the engine, while the fixed tube need not move at all. The sleeve moves slowly under control of the pilot in a fore and aft direction as determined by the pitch of the co-acting threads, rotating slowly as it advances or retreats on the fixed thread. It will be apparent that a much more sensitive control is possible than when direct linkage is employed, though this feature would seem to be one of rather doubtful value to the writer and might be a distinct disadvantage if quick action was necessary in an emergency.

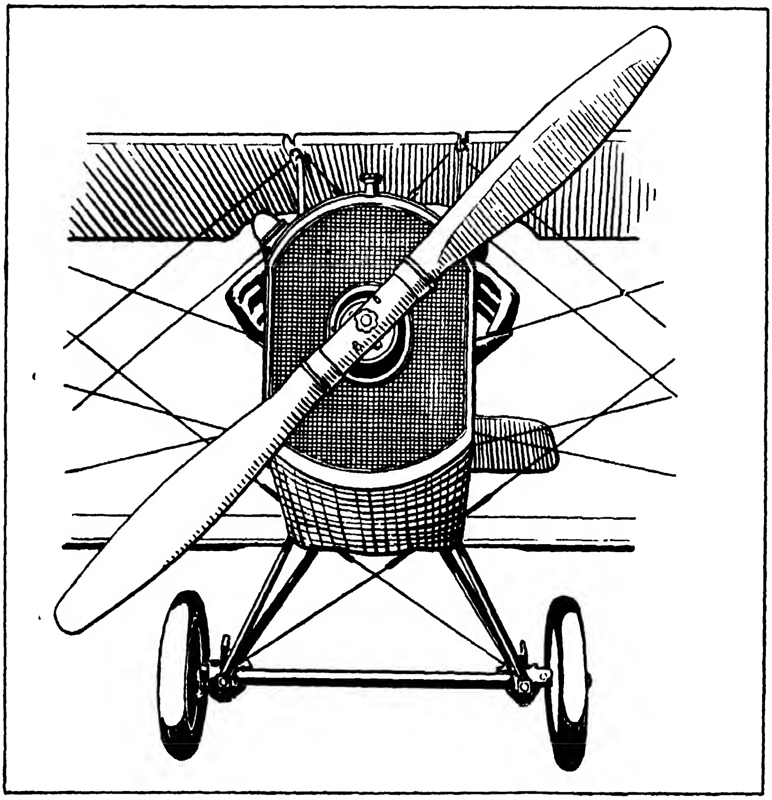


Fig. 231.—Front View Showing Installation of Hart and Eustis Propeller.

Hart and Eustis Variable Propeller.—The Hart and Eustis variable pitch propeller is unique because of the light weight and compactness of the angle changing mechanism, which is very little larger than the propeller driving hub. The installation on a test airplane is shown at Fig. 231. The wood blades are held in metal ferrules, as shown at Fig. 232 and may be prevented from pulling out by suitable dowels or other fastenings passing through the ferrule and into the wood. The blade and ferrule assembly was held in place by a threaded retention member or round nut that fitted

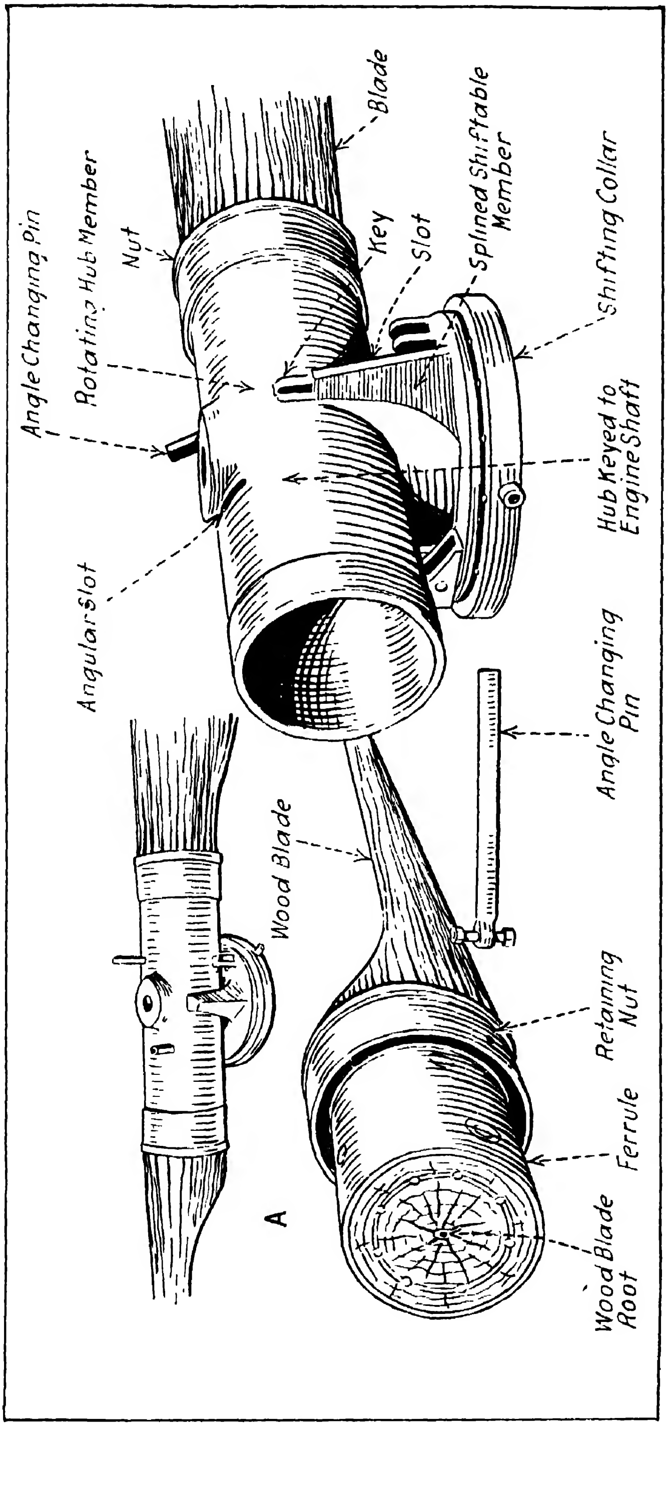


Fig. 232.—Blade Changing Mechanism of Hart and Eustis Variable Blade Propeller.

threads on the hub member. A ball thrust bearing interposed between the retention member and the end of the ferrule resisted centrifugally applied loads and permitted the blades to be displaced angularly by the mechanism supplied for that purpose. The familiar and old principle of pins operating in an angular slot, as has been used for many years in ignition timer automatic advance mechanisms is employed on a larger and somewhat modified plan in this propeller.

The hub is provided with two keys, one of which is clearly shown at Fig. 232, the other being oppositely disposed. A splined shifting member must turn with the propeller hub but can be moved longitudinally on the retaining keys. The shifting collar does not turn as it is separated from the splined shiftable member by a ball bearing. When this collar is pulled back and forth, it produces a corresponding movement of the splined member. This carries lugs to which the angle changing pins are hinged by suitable bolts. These pins pass through the blade ends as well as the ferrule, as shown at Fig. 232 A which shows the assembly of the hub and blades. Angular slots in the hub tubular extensions that serve to drive the blades, cause the blade angles to vary as the pins move in and out because of the movement of the shifting collar. If the pins projected through holes instead of slots and in a plane parallel to the center line of propeller drive shaft, there would be no movement possible of the blade, the pins would merely slide in and out without displacing the blade angularly. Owing to the placing of the pins at an angle to the center line and using angular slots, the blade angle is varied as the collar is pulled or pushed and the sliding pins act as riders on the cams or inclined planes represented by the slots.

Flight and whirling tests have shown the mechanical principles involved to be sound and the latest forms are considerably improved and strengthened over the early form shown in the illustrations which suffice to show principles of action and construction. The first tests made showed that the blades had pulled out of the ferrules to some extent and it was suggested that blades of micarta be molded into the ferrule, which could be provided with inwardly projecting flanges rolled in after assembly to hold the blade firmly in place.

Epicyclic Airplane Propeller Drive Gears.—Airplane propellers, as the writer has previously mentioned operate most efficiently at a speed range of from 1,200 to 1,500 r.p.m. In this speed range it is possible to obtain a large enough propeller diameter to avoid excessive interference between the propeller slipstream and the fuselage and other parts back of the propeller. The most efficient pitch also can be obtained in this speed range. At higher speeds it is necessary to restrict the propeller diameter in order to avoid setting up excessive strains in the propeller due to too high circumferential speed. The most efficient speed of the average modern water-cooled airplane engine, is usually in the range from 1,800 r.p.m. to 2,200 r.p.m. It readily will be seen that a reduction gearing of some sort is desirable, in order to allow both engine and propeller to operate at their best speeds.

In considering a suitable reduction gear for the aviation engine, two important factors enter into the design:

First, the greatest possible efficiency must be realized.

Second, the construction must be light and compact, although at first thought a heavy and bulky construction would appear necessary to withstand the internal stresses created in the transmission of so much power as is developed by the usual large engine.

In the preceding chapter on water-cooled aeronautical motors, the simple and effective reduction gear used on Packard aeronautical engines was shown as applied to the 2A 2,500 engine at Fig. 177. In this the reduction was obtained by a single pair of spur gears, one mounted on the propeller shaft between large anti-friction bearings was meshed with a smaller gear carried by the engine crankshaft below it, this also being supported by anti-friction bearings at each side. The gears are of heat-treated, high strength alloy steel and have exceptionally wide faces to transmit the great horsepower produced by that engine.

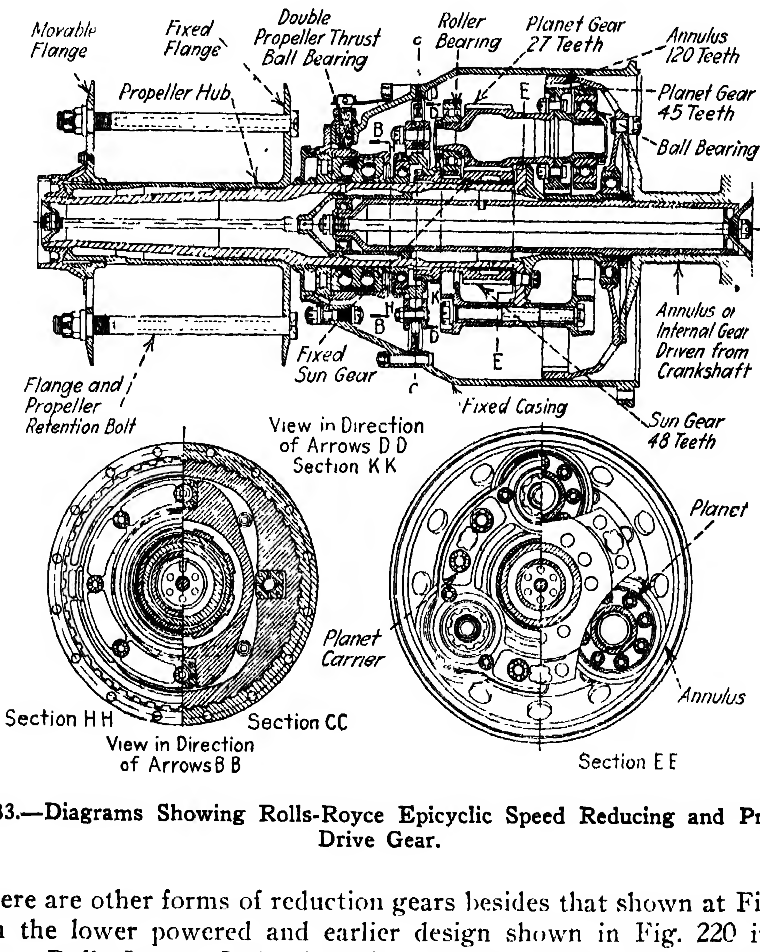


Fig. 233.—Diagrams Showing Rolls-Royce Epicyclic Speed Reducing and Propeller Drive Gear.

There are other forms of reduction gears besides that shown at Fig. 177 and in the lower powered and earlier design shown in Fig. 220 in this chapter. Rolls Royce, Ltd. of Derby, England, have been building for some time past a reduction gear of the epicyclic type for use with their 12-cylinder aircraft engine, and have been very successful with this gear.

This is clearly shown at Fig. 233 and it will be evident that it results in a much neater nose assembly than is possible with the superposed spur gear reduction previously considered.

In considering the design of the reduction gear for the Rolls Royce engine, full attention was given to various types of gears including almost every type which could be considered at all practicable, and the decision was reached that the epicyclic gear gave the best combination of strength, wearing qualities and other desirable features, without too great loss of efficiency.

The form in which only two gears is used is most efficient mechanically, but it cannot be made as compact about the center line and the stress of power transmission produces a strain on relatively few teeth, which must be large to resist it adequately, and of course, considerable tooth friction is present because of high unit pressures. Unit pressures are lower in epicyclic gears because more teeth are in engagement. The factor of bearing friction between the planets and their pins is reduced by using antifriction bearings.

Various methods of compounding plain epicyclic gears have been tried, but the best type is undoubtedly that combining double planets, an annulus driven from the crankshaft, and a sun fixed to the engine casing. One of the great advantages of this type of gear is that the planets are not held on overhanging pins as is the case with plain planets, but are balanced about the flange on the propeller shaft in such a way that the projecting portions of this flange, to which the two halves of the planet cage are bolted, are not put in torsion by the driving load on the planets.

The "Universal" Adjustable and Reversible Propeller.—A device which does for the aircraft what change speed gears do for the automobile is the invention of Spencer Heath, and is built by Paragon Engineers, Inc. of Baltimore, Md. It comprises a system of special blades and a mechanism for varying the pitch of the blades from zero to 360 degrees, while in flight or otherwise and is described in Technical Memorandum No. 155 of the National Advisory Committee for Aeronautics.

By adjusting the pitch, either before starting or while the engine is running, to a less than normal angle, the engine is allowed to pick up speed and deliver its maximum power which is necessary in taking off with a heavier load than the same airplane could otherwise normally carry. Upon reaching the desired altitude, the pitch may be increased by the pressure of a finger on a knob on the dash and the engine run at its most economical speed, still with the possibility of increased speed range, should occasion demand. As the load is lessened by consumption of gasoline on a long distanced flight, the pitch may be still further increased.

In landing, the pitch of the screw may be changed to any degree in the opposite direction, or "reversed" in a few seconds, just before the instant of contact with the ground and the airplane brought to a stop in the very shortest space, obviating entirely any prepared ground system of slowing up the airplane. This is a feature of especial moment to naval or commercial aeronautics where the shortest run after landing is a prime necessity, owing to the confined space which may be available on a ship's deck or even on that of an airplane carrier ship like the Langley, or in small emer-

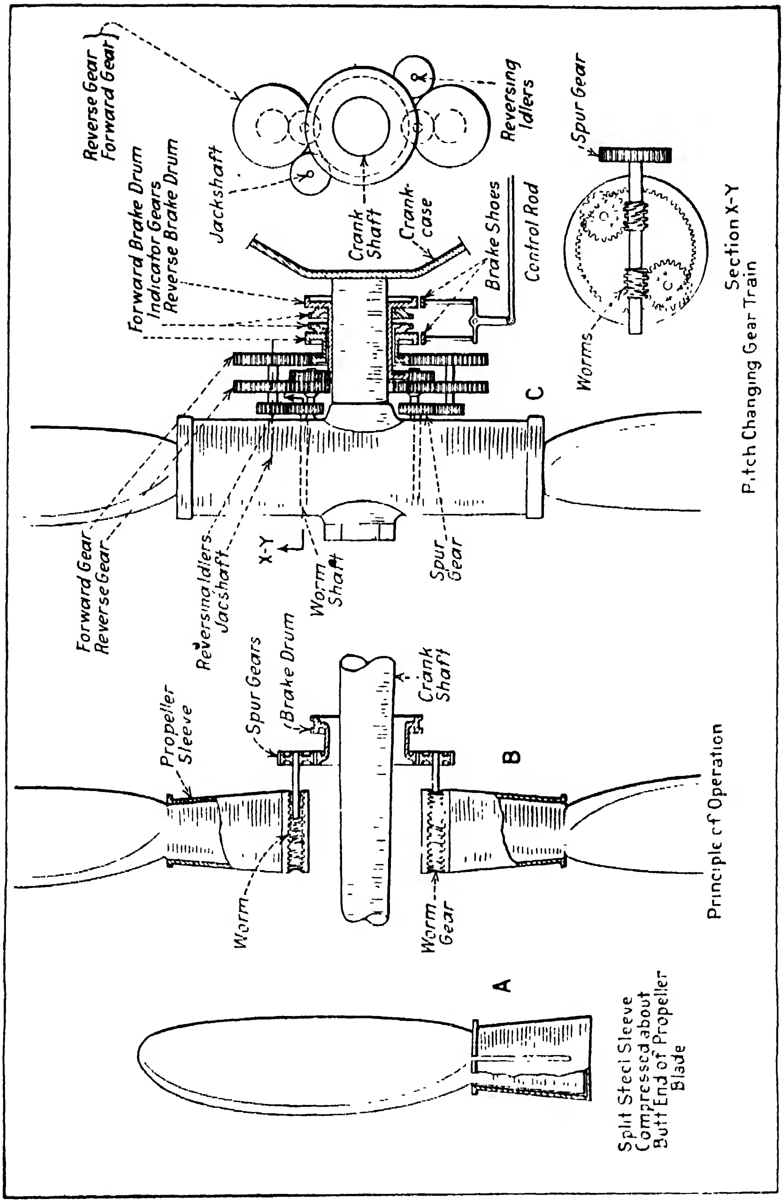


Fig. 23[illegible]—Diagrams Showing Construction of Universal Adjustable and Reversible Propeller: A—Split Steel Sleeve on Butt End of Blade. B—Principle of Blade Angle Changing Mechanism. C—Showing Operation of Pitch Changing Gear Train.

gency landing fields when commercial airplanes might be forced to alight under other than ideal conditions.

For the airship, the same advantages of economy are apparent while the reversible attribute exactly doubles maneuverability in docking, whether shed or mooring mast is employed. It is even possible that the adjustable and reversible propeller may cause rapid advancement in the helicopter, or direct-lift airplane. It has long been realized that the variable pitch and reversible propeller was a development which would travel side by side with supercharged and multi-engined aircraft.

This new design presents many valuable features. In the Heath propeller there has been achieved:

(a) Elimination of continuously running gears, collars or bearings in the pitch control mechanism.

(b) The use in flight of engine power in place of manual labor in changing the blade angle.

(c) The absence of any structural limitation to the range of blade angles available as well as the limiting of the blade travel between any two predetermined extreme positions.

(d) Continuous indication on the instrument board of the blade position.

(e) Automatic throttling of the engine while the propeller is passing through the position of neutral pitch.

The two wooden or steel blades are fastened into steel sleeves which in turn are held in a steel hub, the centrifugal forces being taken on ball thrusts and torsional and axial forces on plain bearings. The method of fixing the wooden blades into the steel sleeves is noteworthy. The butt end of each blade is tapered outwardly at a small angle as shown in A, Fig. 234, and the surrounding collar is split so that it may be first sprung over the butt and then compressed upon the taper.

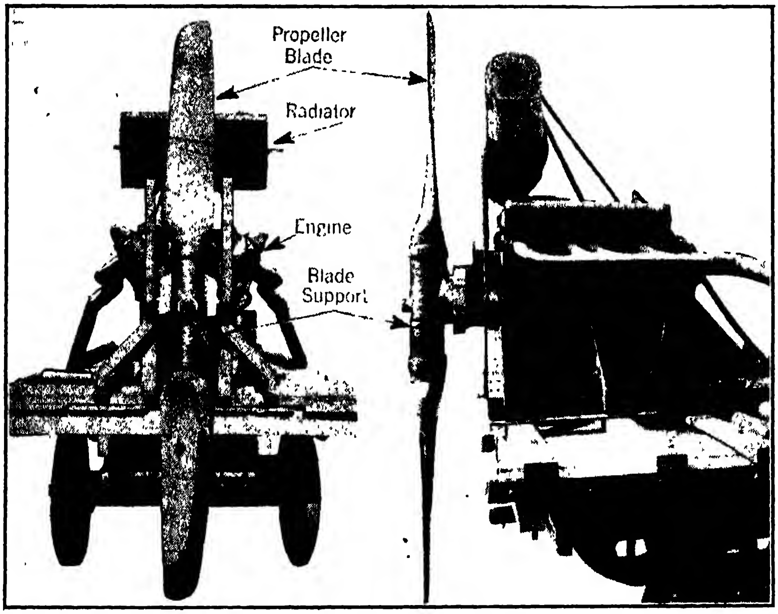


Fig. 235.—Views Showing Method of Testing Universal Adjustable and Reversible Propeller.

Pitch Changing Mechanism.—The pitch changing mechanism is operated through the application of a braking force to either one of a pair of small brake drums surrounding the engine crankshaft and normally rotating with it. The elementary principle is shown by diagram in B, Fig. 234, which represents a brake drum connected through a gear train to the

individual blades of the propeller. It is apparent that if the drum is allowed to revolve at crankshaft speed, all the gears will be stationary relative to the propeller and that the pitch angle will remain constant. If, on the contrary, the brake drum is held stationary the gear train will be set into action and the pitch angle of the blade will undergo a continuous change until the brake drum is released.

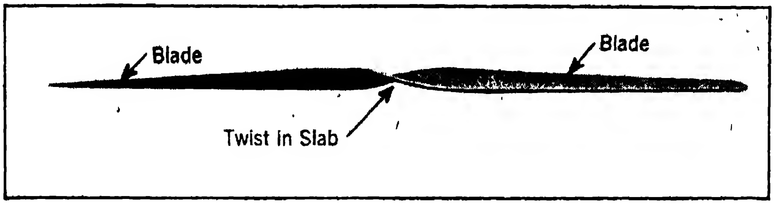


Fig. 236.—Reed 8'7" Diameter Propeller ⅝" Thick at Hub Section, ⅛" at Tip Section Made of a Single Piece of Sheet Metal ⅝" Thick. Pitch is 5 Feet.

In order to change the blade angle in the reverse direction a second brake drum is used, connecting to the worm shaft through an idler which serves to reverse the direction of rotation of the worm shaft. It should be noted that during normal flying none of these gears are operative and that the blades are locked in position by the non-reversible features of the worm and the friction of the connected parts. The actual construction of the pitch changing mechanism is more fully indicated in C, Fig. 234. The brakes are applied through leather faced shoes operated from the pilot's seat by a light push and pull knob attaching to a brake lever mounted on the drum housing. A small hand crank is provided by which the pitch can be changed while the engine is not running.

Fig. 237.—Reed Duralumin Propeller with Twisted Flange Hub.

The angular setting of the propeller blades at any instant is a function of the relative motion which has taken place between the two brake drums. The indicating mechanism is therefore operated by gearing from the two brake drums which conveys differential motion to the indicating pointer and the throttling and pitch-limiting cams. As long as the two brake drums revolve, both at crankshaft speed, the indicating hand remains stationary, but if either of them is retarded, an angular motion is shown on the indicator equal to that experienced by the blades themselves.

The mechanical throttle is provided with springs in both directions so that the pilot can at any time by applying a force on the throttle greater

than the initial tension in the springs substitute manual for automatic control.

In the pitch limiting mechanism the control knob normally connects to the brake levers direct, a push increasing and a pull decreasing the pitch. If the control button is held in either operating position until the limiting position of the propeller blade is reached, the cam trips a latch plate and renders the control inoperative in that direction while leaving it ready for use in reversing the direction of propeller blade motion.

To show the action under power the propeller has been installed on a 150 horsepower Hispano-Suiza engine mounted with gasoline tank, observers' seats, etc., on a trailer truck weighing about two tons, which is free to roll on the ground (see Fig. 235). Demonstrations have been made, the engine and propeller being operated by any one present. In these demonstrations the device is put through its entire range of performance, which includes disconnecting the pitch-limiting mechanism so that the blade angles are controlled throughout a complete revolution of 360 degrees, both forward and reverse. With the engine turning at 1,500 r.p.m., the angular change from full speed ahead to full speed astern is accomplished in about 3 1/3 seconds.

Features of Reed Metal Propeller.—Mr. S. Albert Reed, inventor of the Duralumin propeller that bears his name describes some of the tests incidental to the development of this air screw in Report No. 168 of the National Advisory Committee for Aeronautics, to which the rèader is referred if the complete text is desired. The following information has been selected as being'of general interest and as this type of propeller is becoming popular for application to all types of airplane power plants and as it has displaced wood propellers in numerous installations, its general features merit some consideration other than the brief mention previously made. The blade of the Reed propeller finds its own position of equilibrium at each speed, the bending stresses can be very considerably reduced and the resultant stress made to consist essentially of pure tension. Hence the possibility of using comparatively thin and efficient sections throughout the blade with consequent increase of efficiency. These sections will then lend themselves to high peripheral speeds, and will retain comparatively high efficiencies at velocities exceeding the speed of sound.

The propellers are made from one piece, which is usually a forging or a solid strip, having approximately the shape of the desired propeller in the untwisted form. This blank is annealed and the sections are then shaped by means of suitably shaped milling cutters, after which the pitch is given to the blades by twisting in a rotary press. The propeller is then heat-treated in a salt bath and quenched, whereby it acquires its final tensile qualities. It is afterwards finished by polishing and shaping of the edges.

The hub bosses, which are usually of cast aluminium, are fitted to the center of the blade, and the air screw is ready for balancing and assembly. The twisting of the blades for pitch is effected in very simple presses of low power, and to some extent it is possible to alter a propeller. Retwisting can be effected up to 2 degrees or 3 degrees without heat-treatment, and in some cases slight re-shaping of the sections is possible. Although

an integral propeller, it has some measure of adjustability after trial, an advantage not possessed by the ordinary wooden propeller.

In the proportioning of stresses exerted on the blades, in order to maintain the required pitch, there are involved calculation and formulas which differ in some degree from those used for wood propellers, necessitating a departure from established precedents. There is no doubt, however, but that propellers of this type can be adapted for use up to the highest powers and speeds; in fact, at the present time, they are probably superior in efficiency to any other. Being made of solid duralumin, or an alloy with similar physical properties, and in a single piece, it has no hollow space, weldings or rivets. Its weight is almost the same as that of a wood propeller of the same area; and while the advantages of metal over wood are generally accepted, its superior aerodynamic properties are still the prominent and essential factor. This latter feature is due to the thinness of the blades, the use of which without deformation under conditions of service, has been made possible in the Reed propeller.

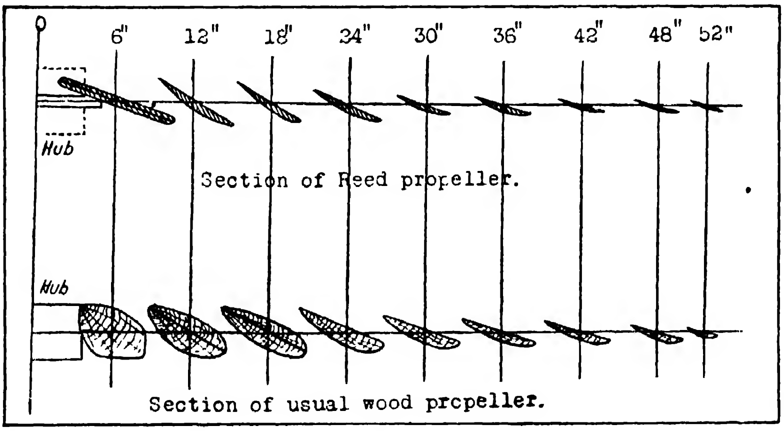


Fig. 238.—Comparing Sections of Usual Wood Propeller with Corresponding Sections of Reed Duralumin Propeller.

This propeller may be classed as semi-flexible. It is made of rolled sheet metal ⅝ inch to 1 inch thick, annealed, and cut to the desired shape. The tapering in thickness is begun a short distance from the hub-center and is continued straight to the tips, at which point the thickness is from 1/10 inch to 3/16 inch. The back surface of the tapered portion is cambered, producing an approved airfoil section, at least, from the 30-inch station out, with lower surface flat and upper surface cambered. The blades are twisted to the proper pitch and heat-treated, after which they are drilled to admit the propeller shaft and then mounted, either on one of the regular wood propeller steel hubs by means of a filler block, or on a specially shaped steel hub as shown in Fig. 237. The propeller is then rigid at the center and progressively flexible toward the tips.

In order to further present the theory of this propeller, attention may be given to Fig. 238, in which the approximate profile of a typical wood

propeller and that of the Reed propeller at the same radii, are given, the peripheral speeds in feet per second for an 1,800 r.p.m. being:

Radii: 6 inches, 12 inches, 18 inches, 24 inches, 30 inches, 36 inches, 42 inches, 48 inches, 54 inches, 60 inches.

F. P. S.: 94.2, 188.4, 282.6, 376.8, 471, 565.2, 659.4, 753.6, 847.8, 942.

The performance of airfoils is generally assumed to agree with the results obtained in wind tunnel experiments which have been made up to 250 ft.p.s. only, with interpolations for greater speed up to 900 ft.p.s., the latter being accepted without question, although based upon assumption. In considering speeds which approach the velocity of sound there is reason, however, for not relying upon interpolation, the indications from results for speeds approaching 1,100 ft.p.s. being that there is no longer only the increase in pressure on the rear surface and a diminution on the front surface, both contributing to a useful thrust, but also a compression wave which accumulates around and on both sides of the leading edge and a similar rarefaction wave at the trailing edge.

These pressure waves spread forwardly as well as aft in relation to the course of the airplane, and, therefore, not contributing to thrust, absorb and waste power. As affecting the velocity of bullets, Professor Boys' photographs of bullets in flight, made first in 1893, and described in "Nature," March, 1893, and also in Smithsonian Institution reports of 1893 (similar photographs are now being made by Major Wheelock at the Frankfurt Arsenal) throw much light on this subject, demonstrating that slowly-moving bullets, having a speed of not over 800 ft.p.s., may have quite a blunt nose without creating a compression wave; but as the velocity approaches and exceeds 1,100 ft.p.s., the compression waves become the chief consideration, and are reduced only by the use of a sharp nose, or a small angle, and a cut-away tail.

In the Reed propeller the blade sections up to approximately 36 inches from the hub-center, travelling at about 600 ft.p.s., could, therefore, have reasonably thick sections with blunt edges, but beyond this station the thinness of profile and sharpness of edges becomes a very material factor; and in the eight or ten inches of the tip, a portion which contributes largely to thrust, it is a matter of serious importance whether or not the leading edge is blunt or sharp, and with a low angle of edge.

Another advantage, by no means negligible, is afforded in the Reed propeller, in the thrust created by the profiles toward the root of the blades. Although comparatively small, this portion contributes to thrust and also produces a cooling blast of air against the nose of the fuselage, which is very serviceable when a radiator is used at that point. The profiles in this portion of a wood propeller, as shown in Fig. 14, are thick and poorly shaped, serving more in the capacity of strength, and do not create enough thrust to carry even their own weight. It may, therefore, be theoretically concluded that the higher efficiency of the Reed propeller is due somewhat to the structure at this point, the determinations, based upon experiments, indicating that the net average advantage gained is at least 6 per cent. Considering radial tension as existing specifically in the Reed propellers on account of centrifugal force; calculations reveal that under a speed of 2,000 r.p.m. the tension does not exceed 8,000 pounds per square inch of

section, and moreover, under 3,000 r.p.m. the tension does not exceed 60 per cent of the breaking strain claimed for the material.

In the matter of pitch constancy when properly proportioned the propeller will maintain its pitch under a power absorption of 50 per cent in excess of that for which it is designed. Other features of value, not contained in the usual wood propeller, will be readily appreciated, i.e. the pitch is adjustable, and on account of the ductility of the material, the blades can be twisted back and forth a number of times without injury to the material until the desired pitch is obtained. Furthermore, in the case of accidents, causing a moderate deformation, it is possible that the original shape may be completely restored. Still another feature, made possible by the thinness and flatness of the blades at the root, is that by crossing a two-blade propeller, a four- or six-blade propeller is easily provided or if preferred, two or more can be mounted in tandem. The manner in which two propellers may be used to make a four-blade air screw is shown at Fig. 323 in Chapter 15 which shows the rear view of the power car of a small dirigible balloon.

Propeller Terms

Miscellaneous

blade back—The side of a propeller blade which corresponds to the upper surface of an airfoil. (Fig. 210.)

blade face—The surface of a propeller blade which corresponds to the lower surface of an airfoil. Sometimes called "thrust face" or "driving face." (Fig. 210.)

propeller:

adjustable pitch—A propeller whose blades are so attached to the hub that they may be set to any desired pitch when the propeller is stationary.

controllable pitch or variable pitch—A propeller whose blades are so mounted that they may be turned about their axis to any desired pitch while the propeller is in rotation. (Figs. 229, 230, 232 and 234.)

propeller blade—See blade back, blade face, blade width ratio.

propeller boss—The central portion of a propeller in which the hub is formed or mounted. (Fig. 221.)

propeller hub—The metal fitting inserted or incorporated in or with a propeller for the purpose of mounting it on the propeller or engine shaft. (Fig. 215 and 219.)

propeller root—That part of the propeller blade near the boss. (Fig. 221.)

pusher propeller—A propeller mounted to the rear of the engine or propeller shaft. (It is usually behind the wing cell or nacelle.)

spinner—A fairing of approximately conical or paraboloidal form, which is fitted coaxially with the propeller boss and revolves with the propeller.

tipping (propeller)—A sheet metal (or equivalent) protective covering of the blade of a propeller near the tip, extended a short distance along the trailing edge and a considerable distance along the leading edge. (Fig. 217.)

tractor propeller—A propeller mounted on the forward end of the engine or propeller shaft. (It is usually forward of the fuselage or wing nacelle.) (Fig. 228.)

Aerodynamical

angle of propeller blade—The acute angle between the chord of a propeller section and a plane perpendicular to the axis of rotation of the propeller. Usually called "blade angle." (Fig. 210.)

aspect ratio of propeller blade—Half the ratio of propeller diameter to maximum blade width.

blade-width ratio—The ratio of the developed width of a propeller blade at any point to the circumference of the circle whose radius is the distance of that point from the propeller axis.

effective helix angle—The angle of the helix described by a particular point on a propeller blade as the airplane moves forward through air otherwise undisturbed. It is equal to the angle whose tangent is the ratio of the velocity of flight to the product of the four quantities: 2π, r (the distance from the axis to the point in question) and n (the number of revolutions per second), i.e.

$$\Phi = \tan^{-1}\left(\frac{V}{2\pi rn}\right)$$

effective thrust—The net driving force delivered by a propeller when mounted on an airplane; i.e., the actual thrust given by the propeller as mounted on the airplane minus any increase of resistance of the airplane produced by the action of the propeller.

indraft (inflow)—The flow of air from in front of the propeller into the blades.

pitch of a propeller:

effective—The distance which an aircraft advances along its flight path for one revolution of the propeller. Its symbol is p_e.

geometrical—The distance which an element of a propeller would advance in one revolution, if it were moving along a helix of slope equal to its blade angle.

mean geometrical—The mean of the geometrical pitches of the several elements. Its symbol is p_g.

standard—The geometrical pitch taken at two-thirds of the radius. Also called "nominal pitch." Its symbol is p_s.

zero thrust—The distance which a propeller would have to advance in one revolution in order that there might be no thrust. Also called "experimental mean pitch." Its symbol is p_t.

zero torque—The distance which a propeller would have to advance in one revolution in order that the torque might be zero. Its symbol is p_q.

pitch ratio—The ratio of the pitch (geometrical, unless otherwise stated) to the diameter. p/D.

pitch speed—The product of the mean geometrical pitch by the number of revolutions of the propeller in unit time; i.e., the speed the aircraft would make, if there were no slip.

propeller area, projected—The total area in the plane perpendicular to the propeller shaft swept by the propeller, excepting the portion covered by the boss and that swept by the root of the blade. This portion is usually taken as extending 0.2 of the maximum radius from the axis of the shaft.

propeller-blade area—The area of the blade face, exclusive of the boss and the root, i.e., of a portion which is usually taken as extending 0.2 of the maximum radius from the axis of the shaft.

propeller-camber ratio—The ratio of the maximum thickness of a propeller section to its chord.

propeller-disk area, total—The total area swept by a propeller; i.e., the area of a circle having a diameter equal to the propeller diameter.

propeller efficiency—The ratio of thrust power to power input of a propeller. Its symbol is η.

propeller interference—The amount by which the torque and thrust of a propeller are changed by the modification of the airflow in the slip-stream produced by bodies placed near the propeller such as engine, radiator, etc.

propeller-load curve—A curve representing the engine power necessary to drive any given propeller at various speeds. The power required varies approximately as the cube of the speed in r.p.m. provided the ratio $\frac{V}{ND}$ remains constant.

propeller rake—The mean angle which the line joining the centroids of the sections of a propeller blade makes with a plane perpendicular to the axis.

propeller section—A cross-section of a propeller blade made at any point by a plane parallel to the axis of rotation of the propeller and tangent at the centroid of the section to an arc drawn with the axis of rotation as its center. (Fig. 211.)

propeller thrust—The component parallel to the propeller axis of the total air force on the propeller. Its symbol is T.

propeller torque—The moment applied to the propeller by the engine shaft. Its symbol is Q.

propeller-width ratio, total—The product of blade width ratio at the point of maximum blade width by number of blades.

propulsive efficiency—The ratio of the product of effective thrust and flight speed to the actual power input to the propeller as mounted on the airplane, consistent units being used throughout.

race rotation—The rotation, produced by the action of the propeller, of the stream of air passing through or influenced by the propeller.

slip—The difference between the mean geometrical pitch and the effective pitch. Slip may be expressed as a percentage of the mean geometrical pitch or as a linear dimension.

slip function—The ratio of speed of advance through the undisturbed air to the product of propeller diameter by the number of revolutions in unit time, i.e., $\frac{V}{ND}$. The slip function is the primary factor controlling

propeller performance. It is π times the ratio of forward speed to the tip speed of the propeller.

slipstream—The stream of air driven astern by the propeller. (The indraft is sometimes included also.)

static thrust—The thrust developed by a propeller when rotating at a fixed point.

QUESTIONS FOR REVIEW

1. What is "pitch" of a screw?
2. What is the difference between a screw working in a fluid and one working in a solid medium?
3. Define "mean-effective pitch," "disc" theory, "blade" theory.
4. Where is the "face" of a propeller blade located?
5. Outline briefly method of making wood propellers.
6. Name important woods used in propeller manufacture.
7. Name some disadvantages of wood propellers and care taken when in storage.
8. Why are wooden propellers tipped and what materials are used for the purpose?
9. Outline main types of metal propellers and describe manufacture of Curtiss-Reed type.
10. What are the advantages of variable pitch propellers and describe a typical method of changing blade angle in flight?

CHAPTER XII

AIRPLANE EQUILIBRIUM AND CONTROL PRINCIPLES

Airplanes Move on Three Axes—Co-incidence between Centers of Pressure and Gravity—Forces Acting on Airplane in Flight—Table XX, Schedule of Weights and Moment Arms in USD-9A Plane—Factors Regulating Equilibrium and Stability—Effect of Wind Gusts—Why Small Control Surfaces are so Effective—Control Methods of Early Airplanes—Standard Control Systems—Functions of Balanced Control—Merits of Different Balancing Methods—Dovetail Balance—Faired Contour Balance—Overhung Balance—Why an Airplane is Banked in Turning—How Rear Stabilizer Works—Adjustable Stabilizers—Control Surface Area—Table XXI, Proportions of Control Surface Area to Main Wing Area—Tail Surfaces and Ailerons—Airplane Control at Low Velocities—Controls Ineffective at Low Speeds—Slotted Wings for Low Speeds—Handley-Page Wing—Wing with Fixed Center of Pressure—Anti-Stalling Gear—Ground Run of Airplanes—Instruments for Navigating Airplanes—Suggestions for the Student in Flying—Run Motor Slowly to Warm it—How to Take-off—How to Attain Altitude and Handle Machine—Precautions when Landing—Danger in Stalling—Control in Making Turns—Flying Learned Only by Practice—Fuel Economy in Flying.

The reader is undoubtedly familiar, in view of the matter previously discussed, with the general principles involved in airplane sustentation and balance. The various parts of the machine have been outlined fully and the functions of the different control elements should be well recognized. Before describing the two most popular control systems it may be well to go a little deeper into the subject of airplane stability.

Airplanes Move on Three Axes.—Aircraft must be capable of movement in three dimensions, and it will be seen by reference to Fig. 239 there are really three axes about which the airplane may move. The longitudinal axis indicated by the line XX is the one that passes from the front to the rear of the fuselage. The lateral axis indicated by the line YY passes from wing tip to wing tip. The vertical axis ZZ passes through the center of gravity of the machine and is the pivotal point about which the yawing movement takes place. This movement is controlled by the vertical rudder which is inclined to one side or the other so that the air pressure against it will cause the tail of the machine to swing toward the side opposite to that to which the rudder is inclined. The lateral or Y axis is the one about which a pitching movement takes place, this being controlled by elevator flaps which regulate the rise and fall of the tail about the axis YY. Whenever the ailerons are operated a rolling motion of the machine takes place with the axis XX as the pivotal line for the lateral movement.

Coincidence Between Centers of Pressure and Gravity.—The important condition that must be observed to secure the steady support of any plane body in the air is that there be a coincidence between the centers of pressure and gravity, or at least that these have such relation to each other that any additional forces brought into play may be counterbalanced. As we have seen, the effect of air in motion under an inclined cambered plane,

or the motion of an aerofoil through the air, is to create certain positive and negative pressures which up to a certain point vary as the angle of inclination of the plane with the relative wind and the velocity of the plane movement through the air. Some of the conditions which must be observed in securing equilibrium are clearly outlined at Fig. 240.

Forces Acting on Airplanes in Flight.—As the diagram at C, Fig. 241, shows, there are four different forces acting upon an airplane while it is in flight. The attraction of gravity, which is represented by the total weight of the machine, acts downward from the center of gravity of the body. The lift is the force opposed to and equal to or exceeding the weight

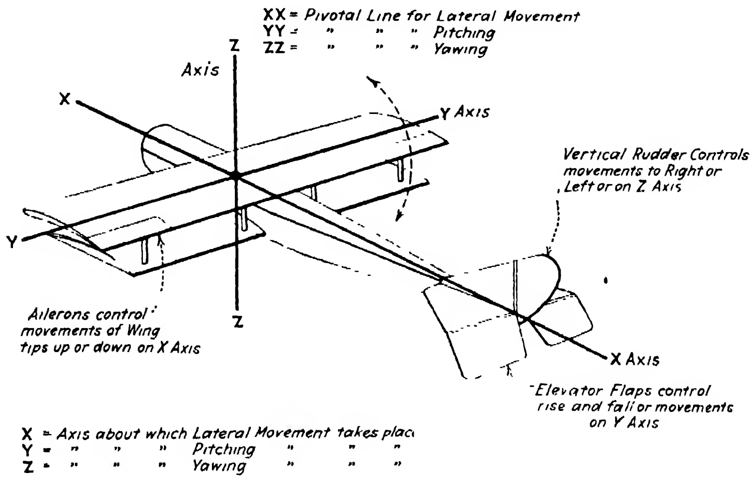


Fig. 239.—A Diagrammatic Representation of the Three Axes about which Movement of an Airplane in Flight may Take Place.

force and acts in the opposite direction or upward. This lift is, of course, created by the supporting action of the wings or some of the other parts of the machine and acts upward through the center of pressure. As has been previously explained, there is a certain resistance offered by the whole machine which is due to both the unavoidable resistance met with in forcing the lifting surfaces through the air and the parasitic resistance (which can be reduced by skilful designing) which is due to the non-lifting portions of the machine, such as the struts, landing gear, bracing wires and skin friction of the fuselage. This force is represented by the line of resistance and it acts through the center of resistance. This must be overcome by the traction or pull of the propeller in a tractor biplane and by the push or thrust of the propeller in a pusher type machine, which force acts through the center of thrust. When an airplane is in normal horizontal flight, it is evident that the traction must equal the resistance or be greater than the resistance and the lift must equal the weight or be greater than the weight. To secure a balance or have the machine in a condition

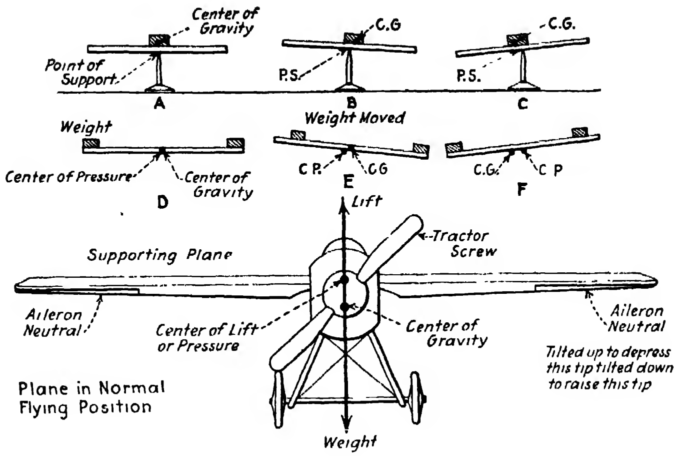


Fig. 240.—At the Bottom is Seen the Effect of the Opposite Forces of Lift and Gravitation to which an Airplane is Subjected in Normal Flight. The Diagrams at the Top Show the Effect of Shifting the Center of Gravity Relative to the Point of Support.

of equilibrium at all times, the forces must meet at the center of gravity of the airplane or the disposition of the centers of thrust, gravity, pressure and resistance in relation to each other must be so that balancing forces will be present. It is not within the purpose of a discussion of this nature to go very deeply into the subject of forces and movements, but it may be well to secure an understanding of some of the simpler rules that must be considered in connection with the arrangement and location of the control surfaces.

We can assume that there is one point on the airplane structure where

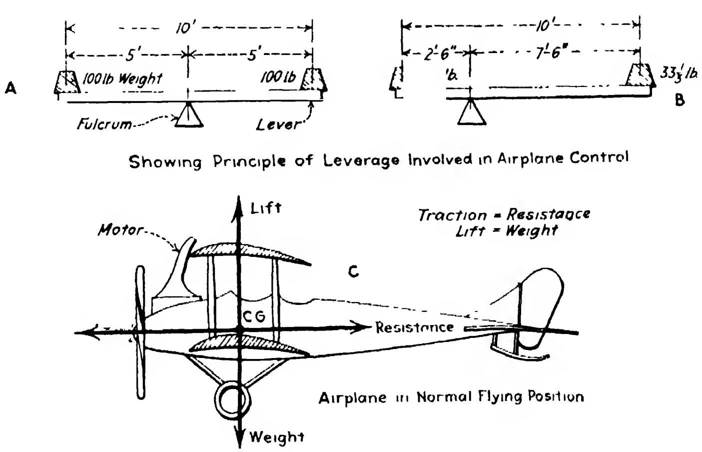


Fig. 241.—Illustrating the Action of Traction, Resistance, Lift and Gravity on an Airplane. At the Top is an Illustration of the Part which Leverage Plays in Airplane Control.

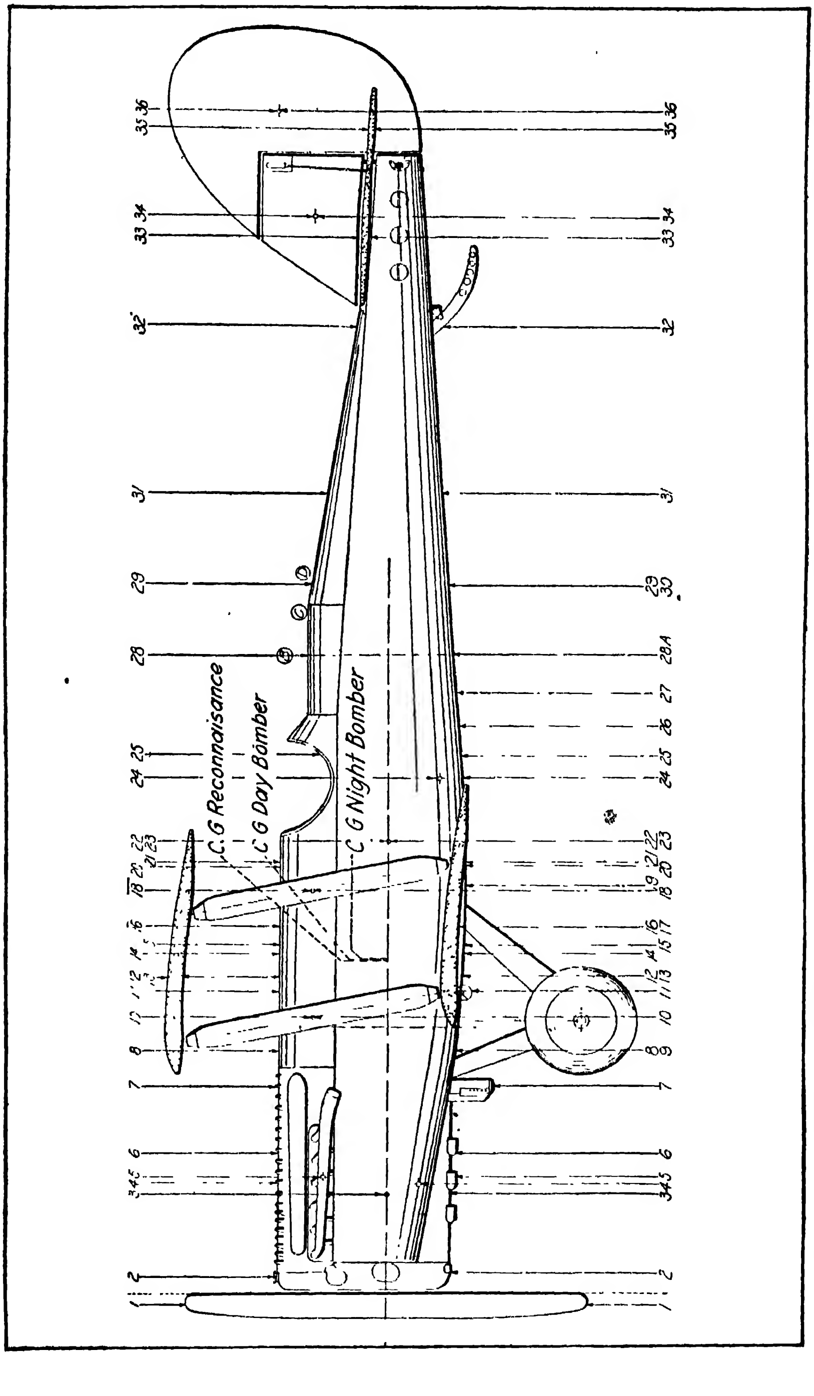


Fig. 242.—Balance Drawing for USD 9A when Used as a Reconnaisance Plane or a Light Bomber. Note Slight Change in C. G. Position. Values for Various Station Numbers are Shown at Table XX.

TABLE XX

Schedule of Weights and Moment Arms—USD-9A—Moments taken about rear face of propeller hub

No.	Member of group and individual weights	Total wt. of groups —lbs.	Arm— in.
1	Propeller, 45.00—hub, 20.75—bolts and nuts, 4.00	69.75	—4.00
2	Radiator, 95.00—contents, 63.00—shutter, 11.50—cowling, 4.60	174.10	6.00
3	Basic engine and additions, 840.90—carburetor control, 4.80—water contents, 37.00—synchronizer, 2.25—engine cowling, 15 00	899.95	29.00
4	Oil tank, 27.75—contents, 96.00—connections, 1.50	125.25	34.00
5	Exhaust manifold, 22 50	22.50	35 00
6	Radiator connecting pipe between radiators, 7.00—contents, 12.00	19.00	40.00
7	Auxiliary radiator, 35.25—contents, 13.00—lift mechanism, 5.00	53.25	60.50
8	Heating and lighting generator, 21.50	21.50	67.50
9	Wireless generator	19.50	67.50
10	Landing gear, complete with cross wiring, 149.00—low-tension wiring, 3.00—front interplane struts, 41.50—aileron control wires, 15 00	208.50	77.50
	Holt flare and wing tip lights	5.50	85.00
	Main gasoline tank, 133 25—contents (134 gal.), 795.00—gasoline tank cowling, 14.00—gun (fixed), impulse cable and thrust tube, 2.50	944.75	86.00
12	Gravity gasoline tank, 16.50—contents (8 gal.), 47.60—connections, 2 25	66.35	89 50
	Upper wing, covered, with ailerons and fittings, 232 00—center wing section, covered, and all fittings, 25.50	257.50	89 50
14	Interplane wires, 38 00	38 00	96.50
15	Wing bombs (50 lbs. x 6), 300 00—wing bomb gear members, removable, 33,25—wing bomb gear members, non-removable, 13.75	347.75	98.75
	Lower wing, covered, with ailerons and fittings, including wing skids, 240 00	240.00	103 50
17	Wing skids (included with group 16)	......	......
18	Rear interplane struts, 37 50	37.50	112 50
19	Ne k (included		
20	Gun (fixed) and attachments, 24 50—gun mount and chute, 6 25—gun cowling, 10 50—ammunition box, 6 55—250 rounds ammunition, with belt, 49 20—windshield, 2 90—Aldis sight, 3 38—ring-and-bead sight, 0 45	103.73	123.50
21	Fuselage bombs (110 lbs. x 2), 220 00—bomb-gear, 4.00—bomb-gear brackets, 2.00	226.00	123.75
22	Instruments, front, 13.04—storage battery, 10 75—storage-battery box, 1.50	26 29	127.50
23	Fuselage (includes all built-in parts), 340 00	340.00	127.75
24	Pilot, 180 00—clothing, 7 00—seat and belt, 11 00—rudder-bar, 3 00—oxygen system, 51 00—stabilizer control wheel, 2 00—radiator control lever for shutters, 3 50—auxiliary radiator control wheel, 1 25	258 75	145 00
	Aileron and elevator control, complete, 22.00—gun (fixed) operating control, 1 25	23.25	150.00
26	Wireless tuning and filter box, 18 75	18 75	160.00
27	Interphone box, 4 00	4.00	169 00
	Cockpit light, 2 00	2 00	175 00
	Bombing observer, 180.00—clothing, 7 00—seat and belt, 11 00—instruments, rear, 2.70—scarff mount, 26 00—guns (turret) with mounting and bags, including magazines loaded, 62.50—Wimperis bomb-sight, 4.35—bomb-sight trap door, 2 33—bomb-release handle, 2 00—rudder-bar, rear, 2.00—fire extinguisher, 6.50—interphone and wiring, 2.75	309 13	179.00
28A	Reconnaissance observer, 180 00—clothing, 7.00—seat and belt, 11 00—instruments, rear, 2.70—scarff mount, 26.00—guns (turret) with mounting and bags, including magazines loaded, 62 50—bomb sight trap-door, 2 33—bomb-release handle, 2 00—rudder-bar, rear, 2 00—fire extinguisher, 6 50—interphone and wiring, 2 75 extra camera magazine, loaded, 8.25—wireless fair leads, antennae, reel and weights, 8 70	321.73	179.00
	Very pistol and twelve cartridges	5.00	197.00
29	Camera with plates, cradle and windscreen, 37 75—release mechanism and adapter, 3.30	41 05	200.00
	Rear light, 0 75	0.75	200.00
30	Three-tray rack with loaded magazine, 26 25—five-tray rack with loaded magazine, 43.25	69.50	200.00
31	Fuselage tail cowling, 10.00—control wires for elevator, rudder and stabilizer, 9 20	19.20	225.50
32	Tail-skid, complete, 8 30	8 30	273 00
33	Stabilizer and bracing, 33 00	33.00	298.00
34	Fins and attachments, 8.00	8.00	303.50
35	Elevator and attachments, 18.60	18.60	328.00
36	Rudder and attachments, 13 85	13.85	333.00

the sustaining effect will be centered and this point, known as the center of pressure will be as shown in the lower portion of Fig. 240, approximately on the line of the main wing spars at the center of the fuselage and is sometimes known as the center of lift. The center of gravity is that point in a body where all other parts acted upon by the attraction of gravity balance each other about it in every position. The force of gravity acts in parallel lines on every part of a body regardless of its shape and therefore the center of gravity must be that point through which a resultant of all these parallel forces is directed in every position of the body. Attention of the reader is directed to the diagram at Fig. 242 which shows what is known as a "balance" drawing among aeronautical engineers. The various groups comprising the total weight are numbered, and by consulting the schedule of weights and moment arms enumerated in table XX for corresponding numbers, it will be evident that a very careful disposition of weights is necessary to secure balance of the airplane.

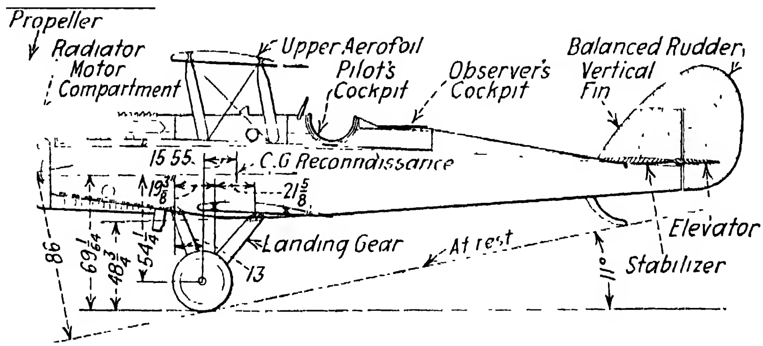


Fig. 243.—USD 9A Reconnaissance Machine, an Obsolescent Type, in Flying Position Showing C. G. on Line of Propeller Tractive Effort.

If one considers a ball or sphere of uniform density, the center of gravity would be exactly at its center. The location of the center of gravity in irregular shaped objects depends upon where the greater portion of the weight lies. Naturally it will be nearer the heavy parts than the light parts. If one considers the sketch of the airplane shown at Fig. 243, which shows a side view of a DH9 reconnaissance plane, a wartime design now obsolescent, the approximate location of the center of gravity may be readily determined. It is near the front end of the machine because the power plant and fuel tanks, which are the heaviest parts, are carried at that end. As will be observed, it is situated at a point about one-third of the chord of the lower wing, where the center of pressure for that wing is located. In the flying boat shown diagramatically at Fig. 244, owing to a different disposition of power plant weight, the engines, in this case, (not shown in diagram) being mounted in the wing structure, the center of gravity is also located at the best point in relation to the wing structure and the center of support of the aerofoils, despite the weight of the overhanging front portion of the boat hull. The center of pressure shifts according to the angle of incidence and flying speed but it does not

vary enough from the center of gravity to prevent proper balance being obtained by manipulating the tail controls in the range from zero to the "burbling" point.

Factors Regulating Equilibrium and Stability.—To secure stable equilibrium of any body the point of support should coincide with the center of gravity. In considering the support of a body having three dimensions we must accept the base at that area on a horizontal plane which is comprehended by lines joining the extreme points of contact. Thus, the base of a box would be represented by a rectangular area while the point of support of a steel ball on a non-yielding surface would be a point. The larger the base the more stable a body is. The slightest touch will set a ball rolling, while it takes considerable effort to disturb the equilibrium of a box.

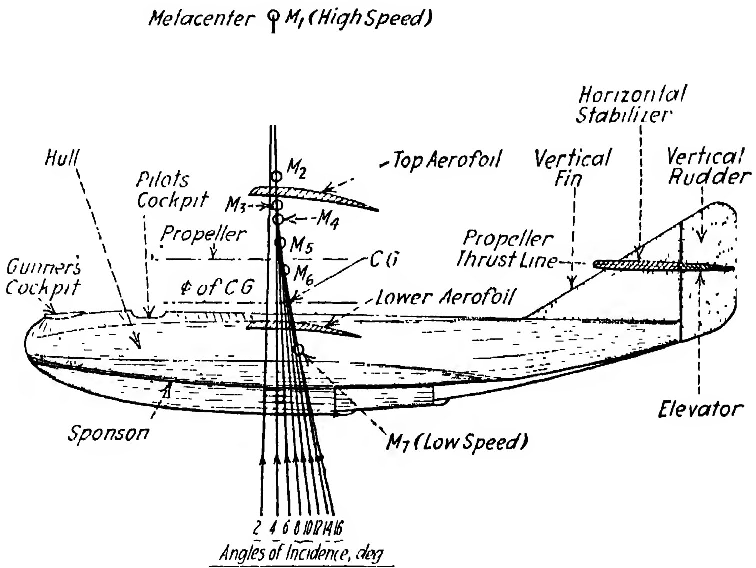


Fig. 244.—How Metacenter Changes in Flying Boat-Seaplane with Changes in Angle of Incidence. Note Location of C. G. below Thrust Line.

If a vertical line drawn from the center of gravity, which line is known as the line of direction or metacenter falls within the base of the body, it is said to be in stable equilibrium. If it falls at or near the edge or base of the body, it is in unstable equilibrium, and the slightest force will cause overturning. This point can be readily demonstrated by tipping a box so that it will stand on one of its edges instead of on its side or base. If the line of direction falls outside the base, the body is not supported.

What is true of a body supported on some solid substance applies just as well to a plane supported by air reaction. This point can be made clear by examining the illustrations at top of Fig. 240. In this case a pivot is used as a point of support and a block is carried by a plate which is supported by the pivot point. At A the center of gravity is directly over the point of support and the plate is balanced. At B, the body has been shifted on the plate, the latter being undisturbed. The center of gravity of the

combination is now to one side of the point of support and the plate is in unstable equilibrium. Referring to D, instead of being supported by a solid pivot point, the plate representing an aerofoil is supported by air and two weights are provided, one at each end. If the weights are so placed that their centers of gravity are the same distance from the center of the plate, the center of gravity of the combination may be assumed, for the simplicity of illustration to be at the center of the plate. The center of pressure, due to air reaction, will be at the same point and the plate will be in a condition of equilibrium. As shown at E and F, moving the weights will change the center of gravity in relation to the center of pressure and cause tipping of the plates. The airplane shown at the bottom of Fig. 240 has the center of lift or pressure directly above the center of gravity and the machine, when in normal flying position, is in a state of equilibrium.

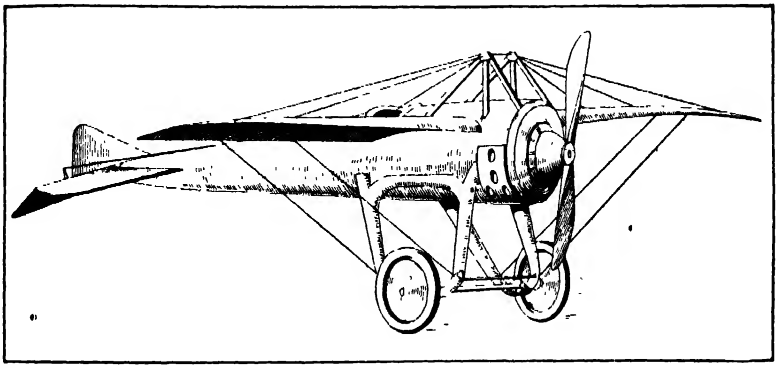


Fig. 245.—The Depardussin Racing Monoplane of 1912, a Pioneer Form Showing Advantages of Thorough Streamlining to Secure High Speed and Compactness in Placing of Weights to Secure Easy Control.

Air Pressure Varies.—As has been previously indicated to some extent, there is a variation in the air pressure upon a plane in flight which cannot be absolutely pre-determined on account of changes in wind movement and temperature as well as altitude of plane. The air itself is never at rest. It moves upward as it becomes heated and moves down as it is cooled and moves sideways, depending upon configurations and nature of the earth's surface which, of course, varies according to locality. There is nothing by which movements or velocity of movements of the air can be predicted or known with certainty for even a brief period in advance. The pressure upon a given area is never constant and, as will be apparent, the center of pressure on an aerofoil will shift constantly and there will be considerable variation between it and the center of gravity.

Effect of Wind Gusts.—For example, a gust of wind striking one side of an airplane in a position of equilibrium will produce added lift on that side if it strikes under the wing, and added weight on the side where its force is exerted if it strikes the upper part of the wing. In either case the effect is the same as though the center of gravity were shifted in relation to the center of pressure or point of support, and the airplane will tip. This movement is counteracted by altering the position of the ailerons from a

neutral position so that the one on the high side is tilted up so the air strikes its upper surface and pushes the high wing down while that on the low side is tilted down so the air pressure strikes its under surface and tends to lift the low wing up.

Why Small Control Surfaces Are so Effective.—The reason why an aileron or other controlling surface of relatively small area may give positive control is because it is carried at the end of the wing and considerable leverage is obtained. Referring to the diagram at Fig. 241 A, we have a condition where lever arms are of equal length, i.e., the fulcrum or point of support is just midway between the two 100-pound weights. The combination is therefore in a condition of balance or equilibrium. As shown at B, if the point of support is shifted so that it will be near one end of the lever it will not take as much weight to balance 100 pounds as it did in the case outlined at A, where the weights were equal. When the long

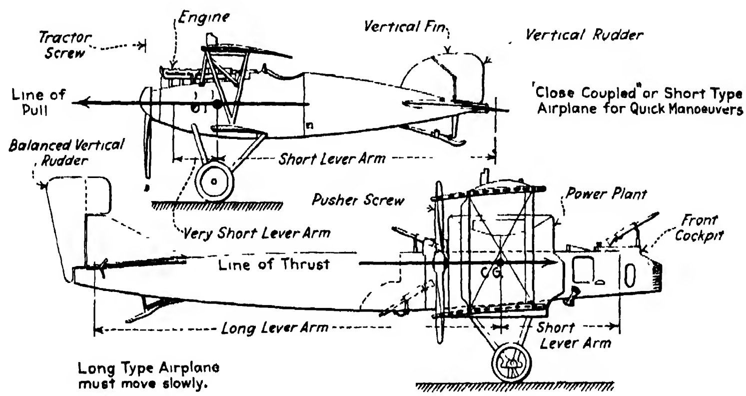


Fig. 246.—The Two Types of Airplanes Used at the Front, Showing the Characteristics of Each Affecting Maneuverability of Long and Short Types.

arm of the lever is three times the length of the short arm, it will take but one-third of the weight to secure a balance. The actual figures will vary somewhat from those used because in the example the weight of the long arm of the lever itself must be taken into consideration, so that somewhat less than one-third the amount of weight mounted on the short arm of the lever can balance it if placed at the end of the long arm.

In an airplane we have a condition similar to that shown at B. The center of gravity of the machine is near the heavy end or front as shown at Fig. 243 and it will take but little weight or pressure at the end of the long arm to balance the considerably greater weight at the front of the machine. In airplane design we therefore have two classes of planes as illustrated at Fig. 246. The short type airplane is the one adapted for quick manœuvers because the lever arms are short and the control surfaces do not have to move as much to produce a given degree of inclination. In the large machines a different disposition of weights, such as produced by having a cockpit for a gunner extending some distance in front of the airplane and engine mounted in the wing cellule will call for a proportionately longer

fuselage to obtain the required balance. An airplane having longer lever arms cannot move as quickly as the close coupled type, so the radial type of engine permits of airplane design that will be easily and quickly maneuvered, because the front or short lever arm is very close to the center of pressure or point of support or to the center of gravity, which is the point about which the designer assumes the airplane pivots when controls are actuated.

Control Methods of Early Airplanes.—The system of plane warping which was used in the early Wright creation by which the supporting wings were distorted at the tips is now obsolete, and all machines of modern design have ailerons or wing flaps to secure lateral control. Longitudinal stability has always depended on surfaces carried far enough back of the center of gravity so that a relatively small inclination would raise or depress the tail, or, in the case of the vertical rudder, would swing it from side to side. In the early days there was considerable variation in the methods of actuating the surfaces for securing a change in direction and equilibrium. The movements required to control an airplane in its flight are usually three.

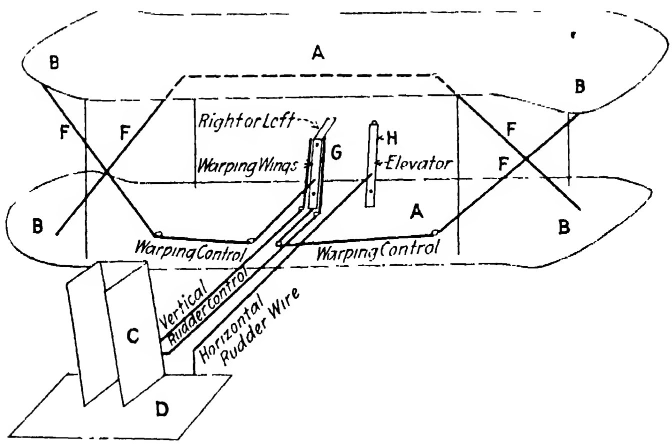


Fig. 247.—Diagram Showing Wing Warping Control System on Early Wright Airplane.

In the early Antoinette monoplane machines steering was by the usual form of rudder bar, elevation was controlled by a hand wheel at the right of the pilot and the lateral balance was controlled by a hand wheel at the left of the pilot. In the early Bleriot, steering was by the feet while a single-lever control regulated the elevation by being pushed forward and backward and the wing warping by being moved from side to side. This was the forerunner of the present stick control system which is almost universally used on the light, speedy types of aircraft. In the pioneer Wright machine steering and plane warping were controlled by one lever while elevation was controlled by another. The pilot had both hands fully occupied, one at each lever. In the Voisin type machines first built, steering

and elevation were controlled by a wheel, the former by turning the wheel and the latter by pushing it and the steering post on which it was mounted, back and forth. Vertical partitions of fabric were used between the planes

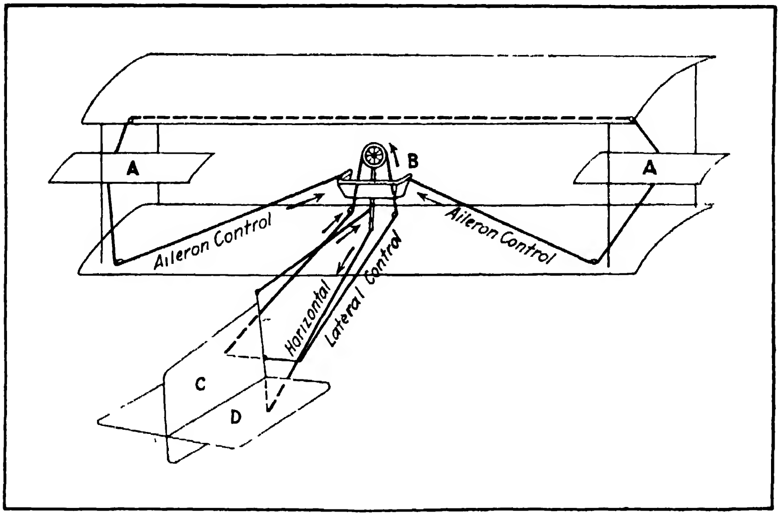


Fig. 248.—Control Systems Used on Early Curtiss Airplanes.

in an endeavor to maintain transverse stability without using either wing warping or ailerons. This system was not successful and was soon abandoned. In the Farman machines, steering to the right or left was obtained with the rudder bar worked by the feet, while a single lever was pushed back and forth for elevation and rocked to the right or left to operate the wing flaps. In the first Curtiss machines steering was by a hand wheel, elevation was obtained by rocking the steering post back and forth, while

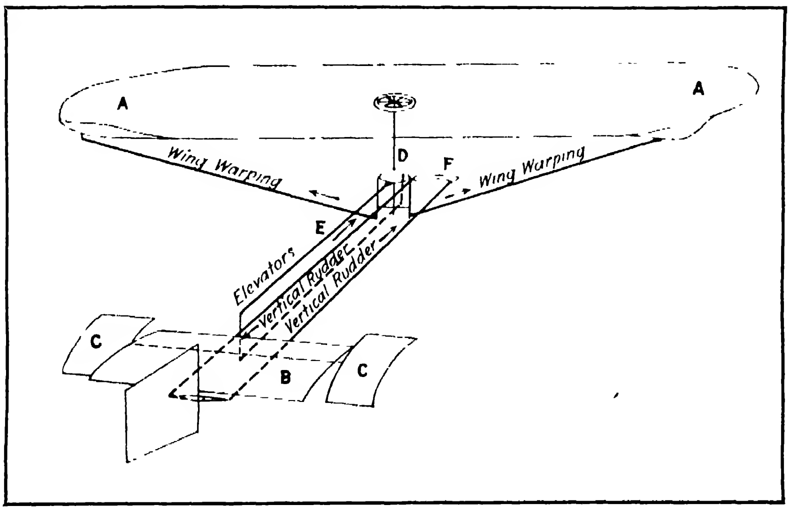


Fig. 249.—The Control of Early Bleriot Monoplanes was the Same in Essentials as the Stick Control now Used.

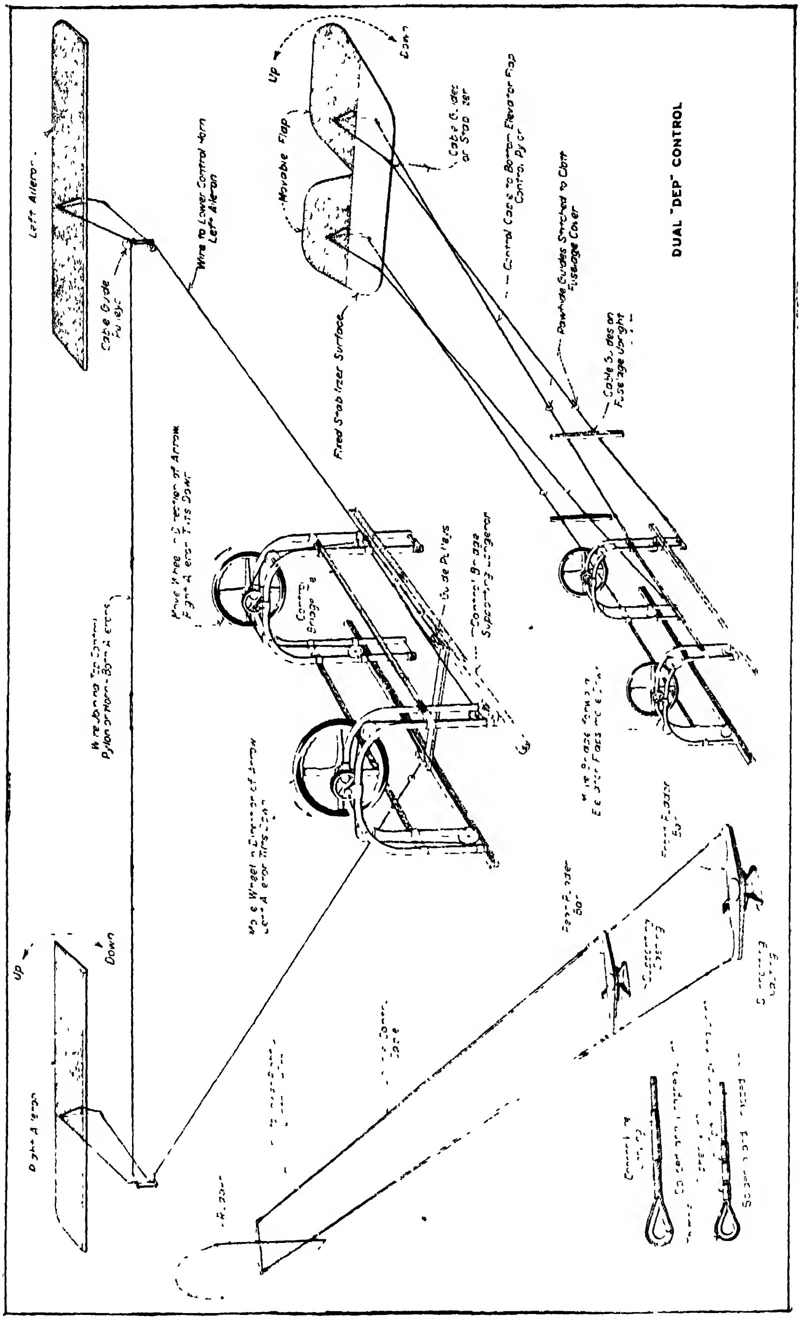


Fig. 250.—Dual Dep. Control System, Showing all Parts and how They are Joined by Control Cables.

the ailerons were actuated by a movable seat back or shoulder rest actuated by the operator's body. It was believed that the operator would lean toward the high side instinctively and by so doing would tilt the ailerons at the high side so the wind would strike the upper surface and move the high side down. (See Fig. 248.)

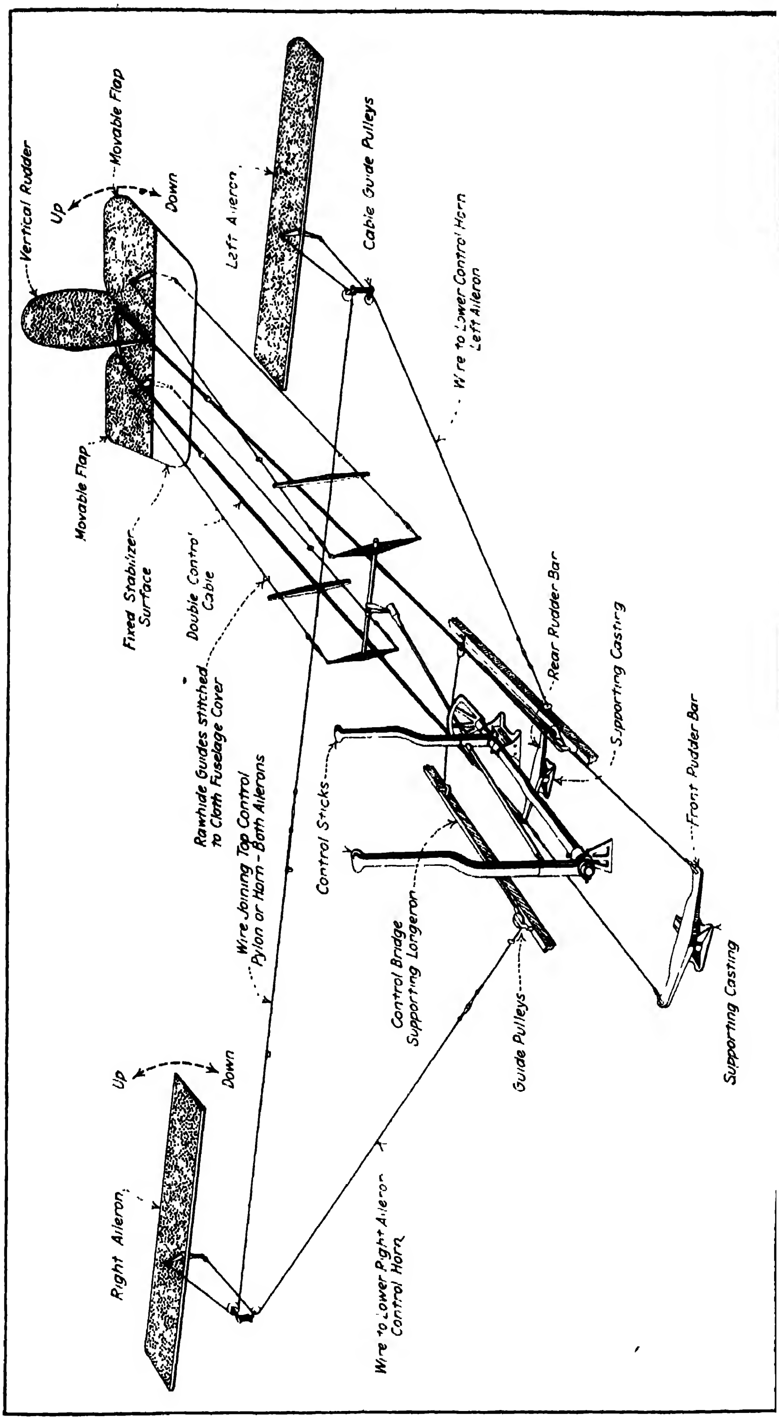
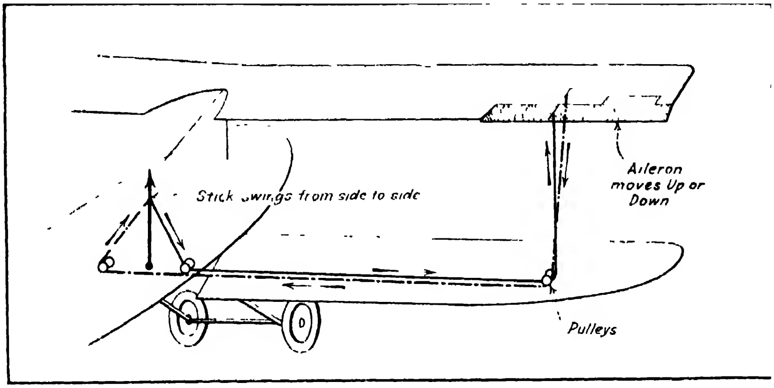


Fig. 251.—Dual Stick Control System Showing all Cables and how They are Connected to the Control Members.

Standard Control Systems.—At the present time but two systems of control are used, the Dep., which is an abbreviation for Depardussin, who invented the system, and the simple stick control. The former is shown

at Fig. 252. It consists of a hand wheel mounted on a control bridge, the relation of the parts being such that the hand wheel may be oscillated at the same time that the control bridge is pushed back and forth as desired. The steering on a horizontal plane is obtained by a foot bar. It is pushed with the right foot to make a right turn and with the left foot to make a left turn. The control bridge is pushed forward to make the airplane go



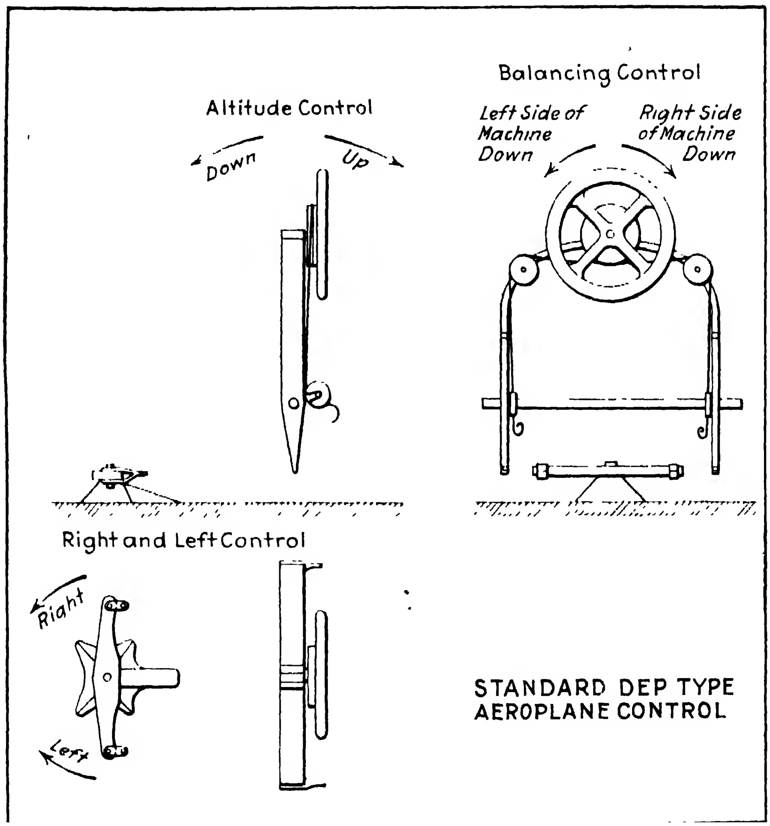


Fig. 252.—How Stick Control Operates Ailerons Shown at Top. Elements of Standard Dep. Type Control Shown below.

down and pulled back toward the operator to make it go up. The balancing control wheel is rocked toward the right side of the machine if the right wing is up and to the left side if the right wing is down. The method of running the control cables to secure the proper movement of the various elements when the dual Dep. system is used is clearly outlined in Fig. 250.

The stick control system, which is shown at Fig. 251, has practically the same movements as in the Dep. system. Altitude control is secured by moving the stick forward to have the plane go down and to pull it toward the operator to have the plane go up. The balancing control is by rocking the stick from side to side. Directional control on a horizontal plane is obtained by the same type foot bar as used with the Dep. system. The diagram at Fig. 252 shows how the cable may be connected up to operate the aileron by means of the stick. With the hand wheel the cable is passed around the control drum or large hub just as in a motor boat steering-gear, or to prevent danger due to slipping, a short length of chain passing over a sprocket actuated by the wheel may be joined to the cable ends. This method is superior to the drum type control, which does not always act positively and which is dangerous. Wheel control is used only on the heavy machines, the stick control being generally used on all small and medium sized airplanes.

Function of Balanced Control.—In order to secure easier control of an airplane and lessen the amount of force exerted by the operator, some airplane designers provide projections from the main control surfaces which assist the operator in keeping the member in the proper position. The Fokker triplane a type used by the Germans in the late war, has these balancing portions on all of the control surfaces. For example, to keep an aileron pressed down against the air reaction requires considerable effort on the part of the pilot, especially on high-speed or large machines. The flap or projecting portion of the aileron, which is on the other side of the pivotal point, receives the air pressure on its lower surface and this force assists the operator in keeping the aileron pulled down. The same thing applies if the conditions are reversed. In this case the air pressure strikes the upper part of the balancing flap and assists the operator in keeping the aileron tilted up. The action of the projecting portions of the vertical rudder and elevator flaps is just the same as that of the similar parts of the aileron.

Various types of balanced control have been used in airplane construction in the past but this practice is not general today. Some designers provide balanced members for ailerons, rudder and elevators, others balance the rudder only, others the rudder and elevator.

For example, the Fokker S3W has all controls balanced, while the Fokker F VII three motored airplane uses balance members on rudder and elevator only. The Loening Amphibian has all surfaces balanced. The Stout-Ford monoplane has only a balanced rudder. Sikorsky, the well known Russian engineer does not balance any of his surfaces. The Travelair planes have the ailerons and rudder balanced. European practice varies as much as American practice does.

Various methods of arranging balancing members are shown at Fig.

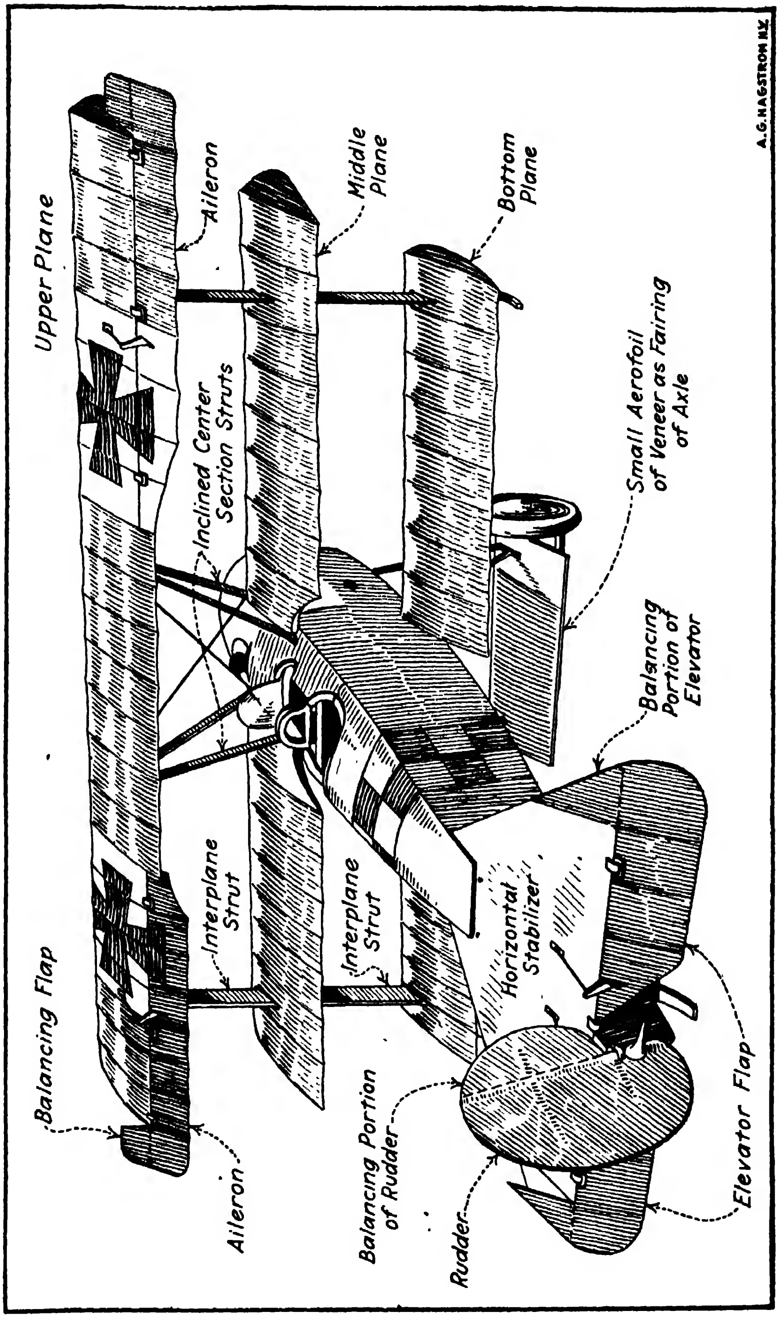


Fig. 253.—Fokker Triplane of Wartime Design with Balanced Control Members.

254. At A is the simple balance used for rudders. The dovetailed balance for rudders or elevator flaps is shown at B. The faired contour balancing flap for ailerons, and sometimes used on rudders is shown at C. A small auxiliary wing is sometimes carried above an elevator or an aileron as shown at D, this being known as an "auxiliary" balance. The overhung balance is shown at E and may be used on any form of control surface.

Merits of Different Balancing Methods.—Commander J. C. Hunsacker, U. S. N., in a paper read before the S. A. E. discusses the matter of the different forms of control surface balancing members and summarizes the matter as follows: "The various means are

(1) Free simple balance as used on the rudders of the NC flying boat and Caproni biplanes and triplanes.
(2) Dovetailed balance as used on the rudders of Zeppelins and ailerons of many German airplanes.
(3) Faired contour balance as used on the Hanriot C3 and Morane Saulnier C2 machines.

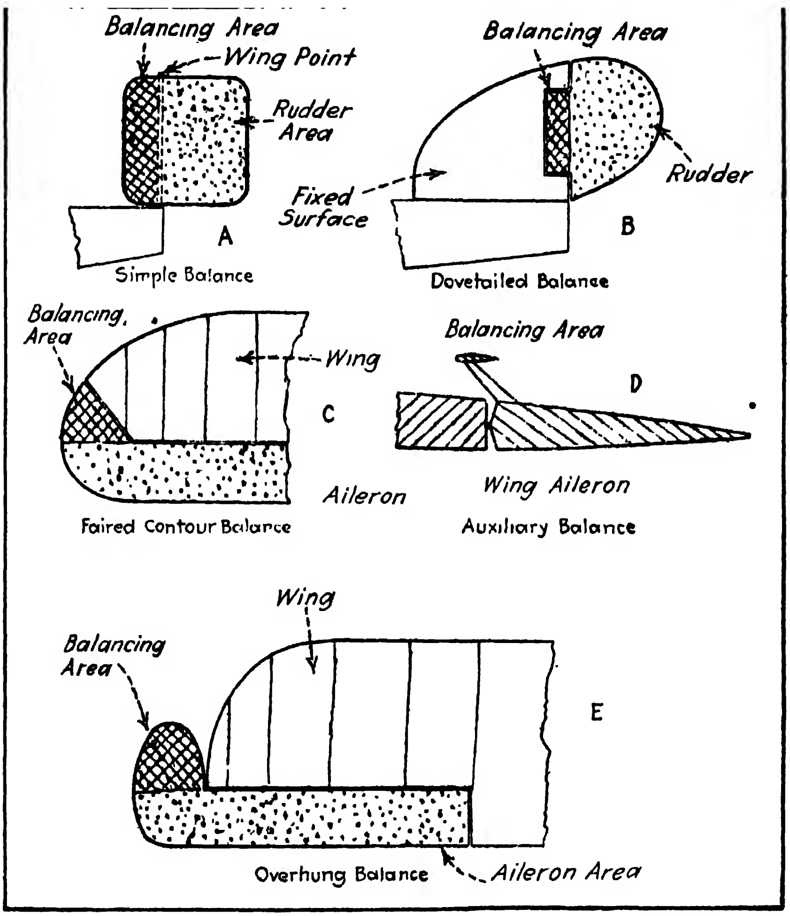


Fig. 254.—Various Methods of Balancing Vertical and Horizontal Airplane Control Surfaces Designed to Make Their Operation Easier for the Pilot.

(4) Auxiliary balance as used on many German seaplanes.
(5) Overhung balance as used on the elevators and ailerons of the NC flying boats, the AEG bomber and Vickers Vimy.

Regardless of the merits of the various types of balancing, the objects of balancing are first, the load on the control cable should be a minimum

for all conditions of flight without overbalancing or fluttering; second, the air resistance of the added balancing portion should be a minimum; third, the added weight should be a minimum; and, fourth, from the structural point of view, the stresses introduced should be a minimum.

The free simple balanced area, if made of a double-cambered airfoil having a small center of pressure movement, can be more nearly balanced for all flight conditions than any of the other types. Owing to the circumstance that it is not preceded by a fixed surface, the area required to give proper control is, however, greater than for a trailing control surface, and the structural difficulty of providing efficient bracing is evident. The free simple balance can, however, be used very advantageously for rudders on machines with a biplane tail, as in the NC boats. There the center rudder is free and is used to balance the two outside rudders. This requires "overbalancing" the center rudder and connecting all three rudders to work in parallel so as to eliminate any tendency of the center rudder to flutter.

Dovetail Balance.—The dovetailed balance cannot be recommended as a good type. If the hinge leakage were eliminated and the movement of the controls at high speeds were very small in amount, this type of balancing would no doubt be ideal from the standpoint of low air resistance. A movement of only a few degrees, however, will introduce a marked increase in drag, and at the same time the action of the airflow on the balancing portion is indeterminate, due to the turbulence introduced. At large angles of the control surface, the balancing portion is blanketed by the preceding fixed surface and the effectiveness of the combination is materially reduced, due to the increased pressure on the back of the fixed surface. This form of balancing is rejected by naval architects, and it is interesting to note that in aeronautics it is becoming more rare.

Faired Contour Balance.—The faired contour balance is often used for ailerons in order to preserve a fair form of wing tip which is supposed to confer some aerodynamic advantage. Such ailerons are quite indeterminate so far as calculation of balance is concerned, due to the uncertainty of the angle of attack of the air striking the balancing portion. At large angle of incidence of the main wings, the air spilling under the wing tips produces abnormally high pressures on the balancing portion of the aileron and may cause overbalance and fluttering. The auxiliary balance has to date been used on only a few machines outside of Germany and its advantages are not well known. The area required should be small, and torsion in the control surface spar due to a balancing portion is eliminated.

Overhung Balance.—The overhung balance, which is perhaps more widely used than any other type, seems to be the most desirable of the types in which a balancing area forms part of the control surface. The extension or balancing portion is working in comparatively free air and should therefore at all times be unblanketed and free from mutual reactions with the fixed surfaces. It is possible to use a double-cambered surface for the extension which will operate equally well for positive or negative angles of the control surface."

Why an Airplane Is Banked in Turning.—Anyone who has ridden a bicycle can appreciate the importance of proper balance, and knows that the faster the speed the easier it is to maintain equilibrium. When round-

ing corners, the expert rider, by proper inclination of his body changes his center of gravity and is able to turn close and at high velocities, while others less expert must diminish speed and make a wide turn. It is well known that it practically impossible to turn a corner at speed without inclining the body enough to overcome the tendency to resist change of di-

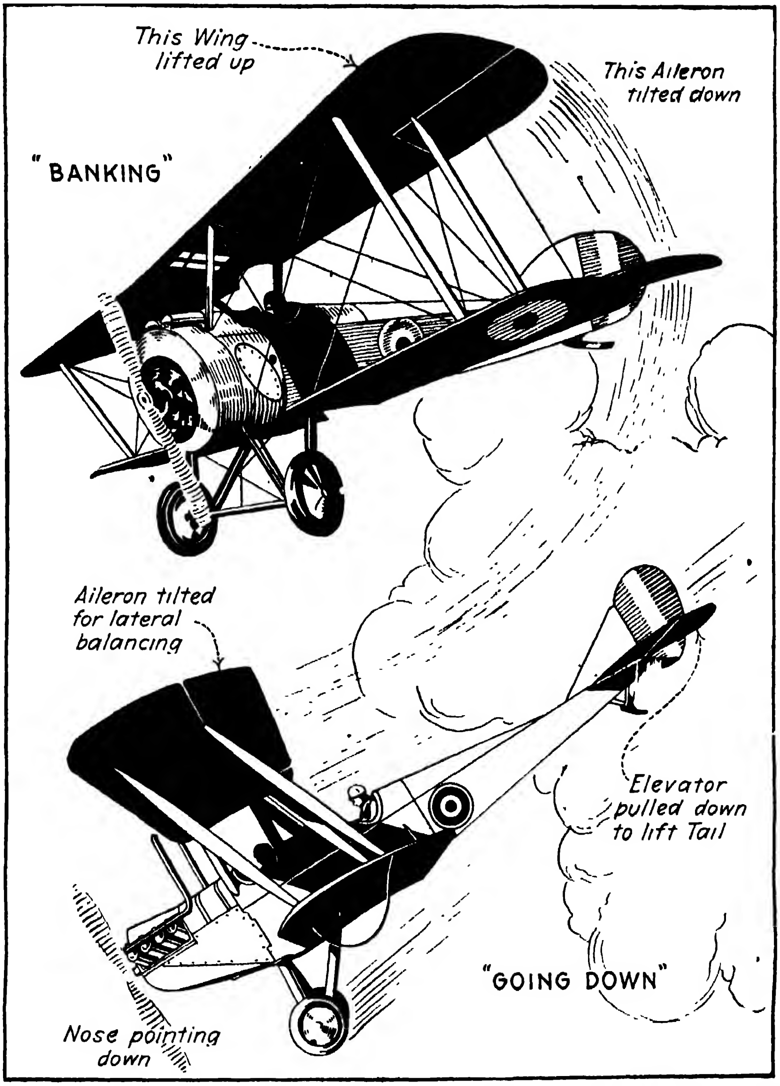


Fig. 255.—Illustrations Showing how Control Elements are Moved to Regulate Airplane Flight.

rection of motion. If we consider the laws of Newton as regards motion, we shall see that the property of inertia is that a body in motion tends to move forever in a straight line and uniformly. Therefore, when turning a corner, by inclination of the body one changes the center of mass enough so that it falls outside of the line of support and both wheel and rider re-

volve for a brief period around the center of gravity, until the turning is completed. After which the rider again shifts his body, so that a line drawn through the center of gravity, known as the line of direction, coincides with the line of support, when proper balance secures travel on a straight line again.

In describing curves with an airplane, practically the same conditions obtain as when riding a bicycle, and suitable compensation must be made

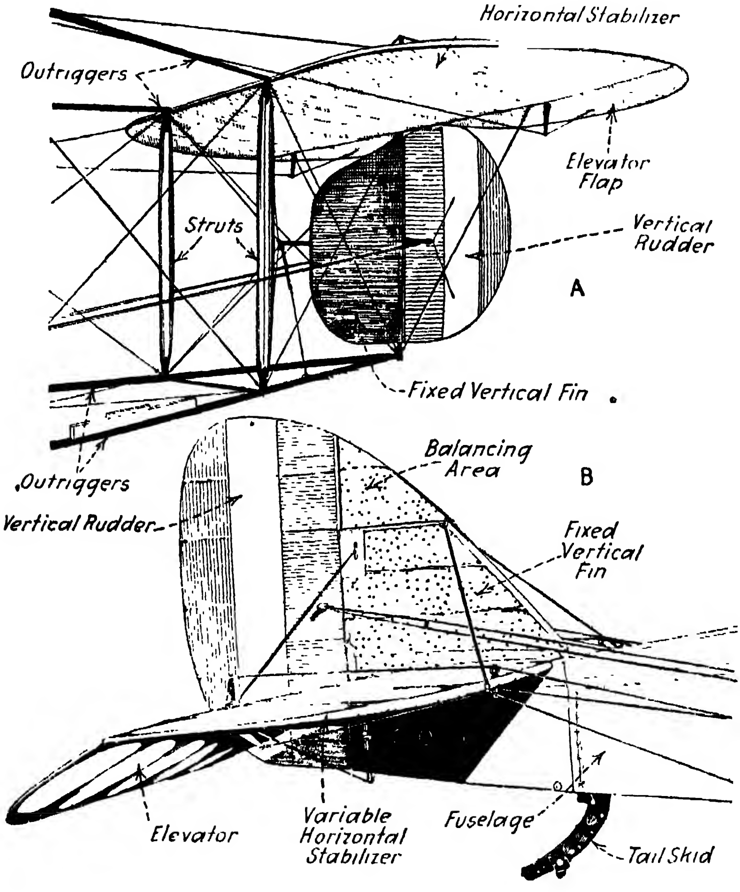


Fig. 256.—Empennage for Airplane Shown at A is the Type Used on Pusher Type Land and Seaplanes. B—Empennage of Typical Airplane Showing all Control and Stabilizing Members.

for the tendency of the machine to throw its inner end higher than the outer in making the turn. This obviously means a loss of lateral stability, and while the rider of a bicycle or a bird can accommodate himself by shifting his center of gravity instinctively, obviously this is not possible with an inanimate piece of mechanism, so the airplane must be "banked" by the lateral control or ailerons if one is to make a turn without "skidding." Any attempt to turn flat, or without banking, always results in a "sideslip."

High motor car speeds are not possible on a circular track unless it is banked, and speeds much greater than sixty miles per hour are hardly possible on circuits less than a mile in circumference that have practically a flat surface. Motorcycle racing has shown that with a properly banked track high speeds are possible even on very small diameter circuits. One can hardly compare the two-point or single-line support machine, such as the bicycle or motorcycle, with either a three- or four-point support vehicle as the tricycle or automobile. In the former instance, the rider's position has material bearing upon the balance, whereas in the other equilibrium at high speed is only obtained by a low placing of the center of gravity and proper distribution of weight. At high velocities even on a flat circular track the cyclist can incline his body and secure practically the same effect as though the track were banked. Obviously this is not possible with a motor car or an airplane and at high speeds the machine skids around instead of running around a corner, unless the track is banked for an automobile or its equivalent is secured for the airplane by banking the wings. The faster the speed, the higher up the bank the car must be driven, as a greater angle of inclination is necessary to offset the tipping tendency of centrifugal force. The same is true of an airplane.

In considering the airplane, one can hardly make a consistent comparison with a motor car, as in this instance four points of support form a base within which it is not difficult to include the line of direction and secure stability, even at high speeds and angles of banking. In the flying machine, we have theoretically but one center of support, and it is somewhat difficult to secure and maintain equilibrium, even in straight-line flight. We have seen that an airplane is supported in the air by the reactions which result when one or more plane surfaces are moved edgewise through the atmosphere at a small angle of incidence, either by the application of mechanical power or by utilization of the force of gravity. In the practical creation there must be provided means for securing both transverse equilibrium, and restoring it when disturbed, in addition to the apparatus for guiding the machine both vertically and horizontally. In turning, an airplane should assume practically the same position as a motor car upon the bank of a track, the outer end being higher than the inner end. In this way air pressure offsets the centrifugal force and "skidding" is reduced to a minimum. The formula in flying is "bank, rudder, rudder, bank," meaning that the control must be actuated in the order named to avoid a "flat turn." The lateral control is operated to tilt the airplane to the proper bank for the radius of the turn and as soon as the banking starts the rudder is operated. In coming out of the curve, the rudder is straightened out before the plane is balanced laterally. Considerable experience is needed to bank the proper amount and a skilled pilot is always known by the manner in which he makes his turns.

How Rear Stabilizer Works.—The function of the vertical fin carried at the rear end of the airplane fuselage and forming part of the empennage is different than that of the stabilizer. A view of a typical empennage of a flying boat where the rear control surfaces are carried on outriggers is shown at A, Fig. 256. The usual arrangement on an airplane or float seaplane is as shown at Fig. 256 B, though of course, the tail skid shown

is used only on land planes, no rear support being needed on the usual design of float seaplane. The reason a vertical fin is used is to steady the rear end of the fuselage in straight flight and prevent too rapid movement to either side when the vertical rudder is manipulated because even the very slight braking effect obtained by a fin of normal area helps. The stabilizer is not only employed as a steadying member, but it also serves a useful purpose in balancing the airplane. If a plane is tail heavy, the angle of incidence of the stabilizer may be set to secure a positive lift while in flight. If a machine is nose heavy, and most modern airplanes are

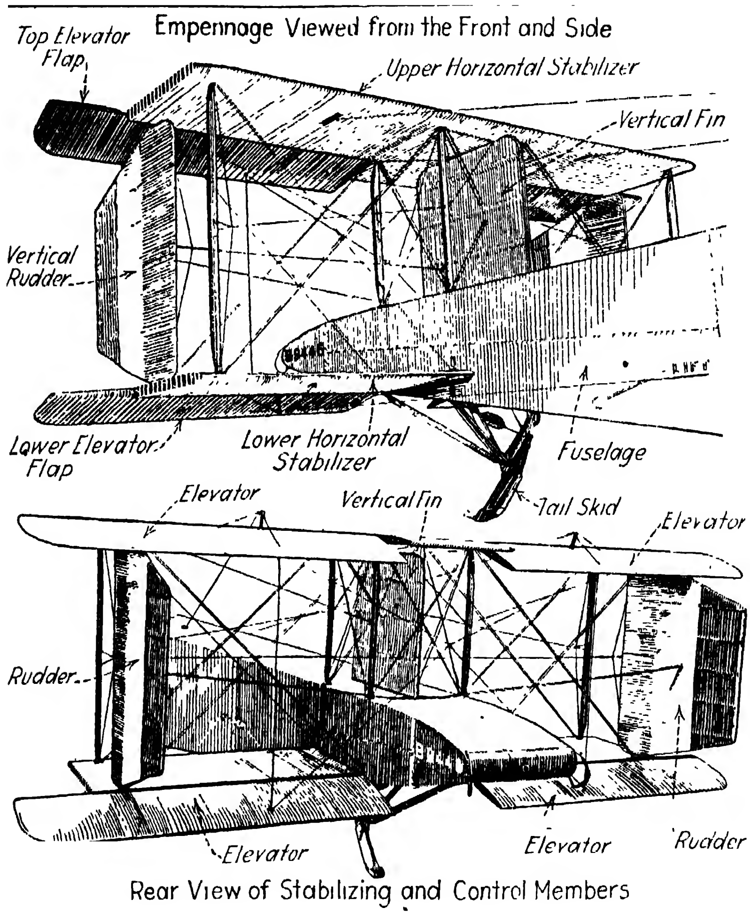


Fig. 257.—Empennage of Handley-Page Bombing Plane Shows Type of Lifting and Stabilizing Structure Used on Heavy Airplanes where Part of the Tail Load Must be Supported by Aerofoils. This Biplane Structure has a Spread Equal to Many Present Day Light Sport Planes.

designed so they are balanced that way, the stabilizer may be set at a negative angle so the tail will be held down while the plane is in flight. It may be set at zero angle and have a double-cambered surface that has practically no lift, in which case it acts just as the vertical fin does and that action can be most easily explained by comparing it to that of the

feathering on an arrow, it assists in maintaining direction of flight without frequent manipulation of the controls.

In very large airplanes used for either military or commercial purposes, which have a wide spread in order to get sufficient wing area, the empennage is often of the weight lifting type as shown at Fig. 257 which depicts the rear end of a Handley-Page bomber. The horizontal stabilizers are really a biplane structure with the elevator flaps hinged to the trailing edges of the aerofoils. The vertical fin is of relatively small area compared to the total stabilizer area. Owing to the large size of the airplane and length of the fuselage, two vertical rudders of the balanced type are provided, as clearly shown. Here, the horizontal stabilizer has a definite duty to perform as it must help in carrying a portion of the weight of the long fuselage.

The vertical rudder control is sometimes connected with a swinging tail skid as shown at A and B, Fig. 258, in order to obtain more positive directional control on the ground at relatively low speeds when the air controls are not as effective as when in flight.

Adjustable Stabilizers.—In various airplanes that have been designed in the past, a certain degree of adjustment was provided so the angle of incidence of the horizontal stabilizer could be changed in flight. The way this was done on the DH9 airplane is shown at Fig. 258 C. A hand wheel placed convenient to the pilot's seat controlled a cable passing around an internally threaded drum fixed against vertical displacement in the back of the fuselage. An externally threaded stabilizer control mast passed through this drum. The stabilizer was hinged at its front end to stationary fittings. When the control mast was rotated, the rear end of the stabilizer was raised or lowered so its angle of attack could be set as desired by the pilot. For instance, starting out on a bombing expedition with considerable ammunition for the machine guns might make the machine tail heavy, if the airplane is a military type. The angle of incidence would then be given a positive or lifting value. When the bombs and ammunition had been expended, the machine might become tail light in which case the angle might be zero or even be given a negative angle which would tend to depress the tail. In the case of a passenger carrying or commercial airplane, a variation in freight load might make such an adjustment desirable, especially if the load extended into the rear of the fuselage to any extent.

Control Surface Areas.—The area of the various control surfaces varies in the different planes and is dependent on a number of factors. Slow flying planes need more surface than fast planes and planes with short fuselages need more surface than a similar airplane with a longer fuselage capable of the same speed. Commander J. C. Hunsaker, U. S. N. made a comprehensive study of numerous types of airplanes and seaplanes some years ago which he detailed in a paper read before the S. A. E. About 80 aircraft of various types were considered and the areas of the control surfaces in relation to that of the wing surface was tabulated. Table XXI gives a summary of average values for the different classes studied, and will show that in some respects, notably that of proportion of aileron surface to wing area, the various types follow very nearly the same proportionate values,

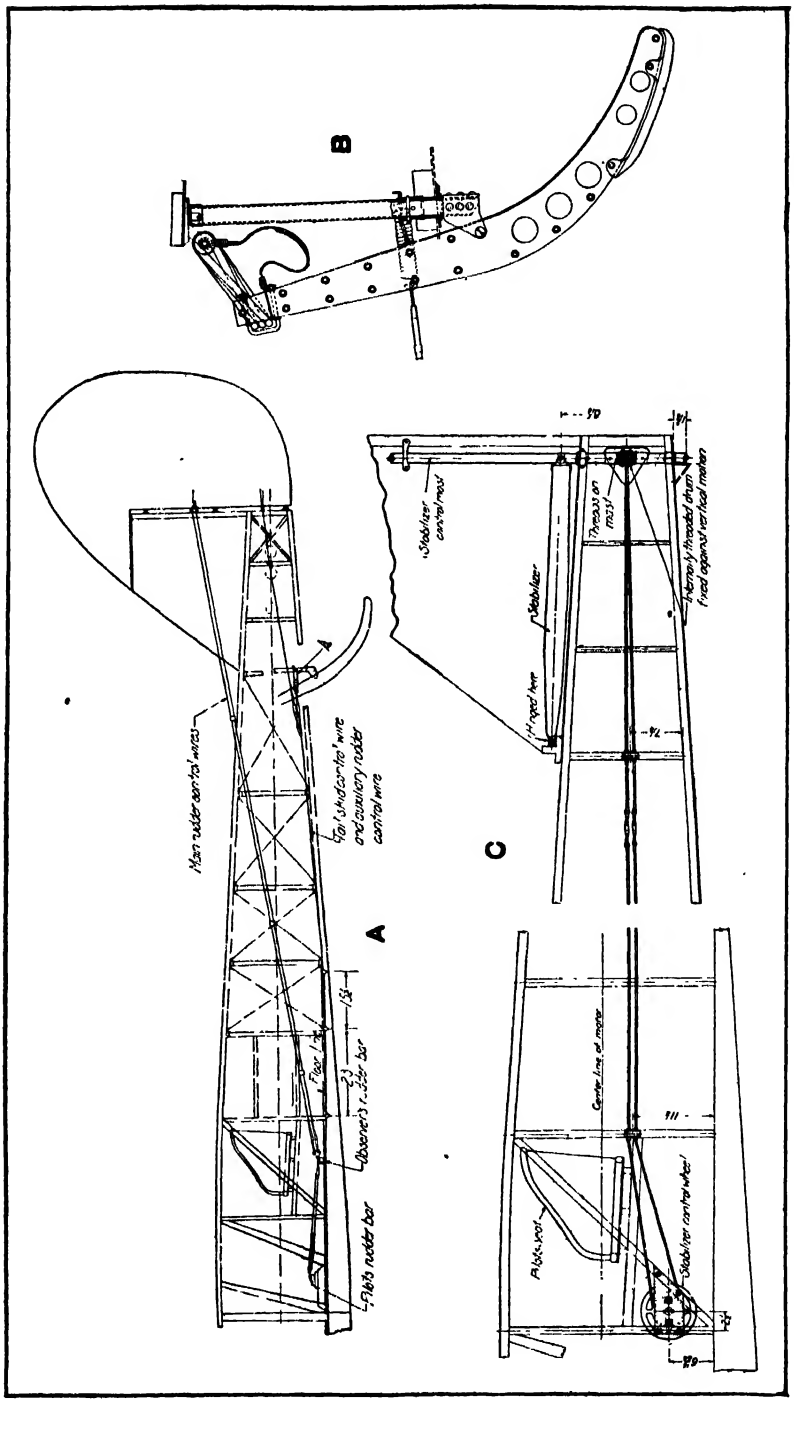


Fig. 258.—A—Diagram Showing Interconnection between Vertical Rudder and Tail Skid. B—Construction of Swinging Tail Skid C—How Incidence of Stabilizer may be Controlled by Pilot while in Flight.

the range being between a minimum of 11.2 per cent to a maximum of 12.9 per cent, the maximum divergence being only 1.7 per cent.

Tail Surfaces and Ailerons.—The necessary horizontal tail surface should depend on the pitching radius of gyration and the degree of maneuverability which are roughly fixed by the procedure of classification by types. Also, the center of pressure motion between high- and low-speed attitudes or the depth of chord and the length of the tail must be important variables. The area of horizontal tail surface should depend on the weight of the machine or on the wing area. The ratio of length of tail to chord length varies from 2.5 for monoplanes to 4.0 for triplanes, and the corresponding average tail surface areas in percentage of wing area vary from 15 to 9. Both theory and the practice of successful designers indicate that the horizontal tail surface depends on chord length and wing area. The triplane with narrow chord has the advantage of requiring a small tail surface.

TABLE XXI

Summary—Proportions of Control Surface Area to Main Wing Area

Number in Class	Class	Horizontal tail surfaces in terms of wing area, per cent (h)	Vertical tail surfaces in terms of wing area, per cent (v)	Aileron surface in terms of wing area, per cent (a)	Distance from tail hinge to center of gravity of airplane in terms of mean wing chord (t)	(th)	(tv)	Aspect ratio (maximum span divided by maximum chord)
8	Monoplanes	14.8	6.1	12.5	2.5	37.0	15.2	5.0
20	Single-Seater	11.8	4.4	12.9	3.0	36.4	13.2	5.9
17	Two-Seater Non-Training	11.7	4.3	12.6	3.2	37.4	13.8	7.3
4	Two Seater Seaplanes	11.4	4.0	11.3	3.3	37.6	13.2	8.7
7	Triplanes	9.2	3.7	11.2	4.0	36.8	14.8	9.6
12	Twin-Engined Bombing Biplanes	11.1	4.2	11.3	3.5	38.8	14.7	9.2
11	Flying Boats	13.8	6.3	11.2	3.0	41.4	18.9	10.4

Table XXI gives the length of tail, or the distance from the center of gravity of the airplane to the tail hinge in terms of the mean wing chord as t and the horizontal tail surface as h as a percentage of the wing area. The product th is there shown to be nearly constant, indicating the reasonable conclusion that long tails can safely be made smaller than short tails. The flying boat class, it will be seen, has an average $th = 41.4$, which is appreciably larger than for any other class. This is no doubt due to the projection of the hull forward of the center of gravity. The twin-engined bombers also have a considerable portion of the fuselage forward of the center of gravity and are seen to require a larger value of th than the other machines. The vertical tail surface v multiplied by the length of tail t in the same notation gives a similar coefficient tv which is larger for the flying boats, as would be expected.

The large value of tv for the monoplanes is not easily explained, but due to the relatively small number of machines listed and the lack of experience with this type, Commander Hunsacker is inclined to attribute this to the designer's desire to keep on the safe side.

The aileron area is practically a constant percentage of the wing area except that small machines which require a great degree of maneuverability have slightly larger ailerons. Apparently the span has very little effect on the required aileron area. The reason for this may be that the machines of high aspect ratio, the bombers and flying boats, are not required to maneuver rapidly. The average aspect ratios are given on Table XXI as a matter of interest. Experiments, both wind tunnel and full scale, indicate that although a long narrow aileron is not quite as effective in producing roll for the same angle of throw, nevertheless the moment about the hinge, which is a measure of the pilot's effort, is considerably less, and for this reason with the same percentage of wing area long narrow ailerons are more efficient than short deep ones. By using especially long narrow ailerons the percentage aileron area given in the tables might be somewhat reduced. The aileron surface in terms of wing area percentage for various wartime German machines as computed by Commander Hunsaker follows:

Name	Aileron Surface in Terms of Wing Area, per cent (a)
Palz Single-Seater	8.9
Friedrichshafen	8.0
Gotha	11.4
A E G	5.4
A E G Armored	11.8
Pfalz Single-Seater	8.9
Pfalz DX II.	7.5
Albatross D-5	7.9
Fokker D-7	5.2
Fokker E-5	7.9
Rumpler C-4	9.6
Hannoveraner	9.1
L V G—CV	6.3
Rumpler G 117	8.4
Roland D-2	6.7
DFW—C-5	6.3
Average	8.0

Airplane Control at Low Velocities.—The main problem that confronts airplane designers who are working on airplanes to be flown by persons of ordinary skill as contrasted to those to whom flying is a sixth sense is that of control at low flying speeds. It is possible, by a careful study to design aircraft which call for a minimum of control because they are inherently stable. Much depends on the relative locations of the center of pressure and center of gravity. If the former is located ahead of the latter we have a tail heavy condition that must be corrected by a stabilizer of aerofoil form, cambered to secure sustentation and set at a positive angle of incidence to obtain lift. As this is an aerofoil, just as the main wing is, it will "stall" at approximately the same angle, as its "burble" point is the same as that of the wing. As the tail loses lift the angle of incidence of the main plane increases even beyond its "burble" point and the stall is aggravated. Modern design places the center of gravity either in coincidence with or ahead of the center of pressure and in normal flight, the plane is

slightly nose heavy and the angle of incidence of the rear stabilizer is set at a negative angle so it will depress the tail.

Suppose a pilot overcontrols his airplane so the main aerofoil reaches its critical angle of incidence. The rear tail surface, which in normal flight has a negative angle of incidence, may under these new conditions, assume an angle of attack that will have a positive lift value and the tail will be lifted, automatically bringing the main aerofoil to an angle of attack below the critical or stalling angle. An airplane, when balanced in this way, will drop its nose and increase its flying speed automatically. Wings of the thick camber or high lift variety are well adapted for use in "non-stalling" airplanes, because the "burble" point is reached more gradually than in thin section wings.

The Fokker three-engine monoplane recovers from a stall automatically, in fact, it is impossible for a pilot to stall it and if it loses flying speed, instead of going into a spin or headlong dive, it flattens out and falls on an even keel. The concensus of modern opinion seems to be that the best airplane for average pilots is not one that is absolutely and automatically stable, nor is it one that must be kept balanced by constant operation of the controls. It should be in neutral stability, equilibrium being maintained by the controls but at the same time, not necessitating frequent manipulation. Many modern airplanes can be flown at constant altitude with "hands off" the controls.

Controls Ineffective at Low Speeds.—It has been pointed out that control surfaces are ineffective at low or stalling speeds so any improvement in design that will increase their efficiency under such conditions will be of value, provided this is not accomplished by the sacrifice of some other equally important feature. It is stated that great reductions in stalling speed of airfoil have become possible with the development of Handley-Page and Lachmann slotted wings. Whereas the angle of stall of the average wing is around 16 degrees incidence, the slotted wings have increased this angle to as high as 45 degrees in some cases. This has made for considerable reduction in landing speed but does not eliminate the danger of "stalling."

Slotted Wings for Low Speeds.—It has been stated that the combination of the slot principle with normal ailerons gives the advantages of a delayed stall together with maintenance of lateral control at low speeds. In such a device, a Handley-Page wing with slot near the leading edge is combined with an aileron of such form so that as the aileron is depressed, a slot at the rear wing spar is opened as at Fig. 259 A with the result that in high lift wing sections a marked increase in rolling around the X axis (See Fig. 239) without a corresponding increase in yawing moment may be secured. In some cases, twice the rolling control may be obtained with but little increase in yaw. The Handley-Page wing slot,is controllable, and it has been advanced that the slot in the leading edge of one wing, that falling, be opened to prevent "burbling" and closing the slot in the rising wing so it would "burble." The slots would be operated in conjunction with normal ailerons. It is claimed that if the slots are used in this manner that a large increase in "rolling" or lateral balance can be obtained with existing controls at low speeds.

In discussing the "Control of Airplanes at Low Speeds" in Aviation, W. Lawrence Le Page outlined some experiments he had made for the Aeronautical Research Committee (British) and reported in Reports and Memoranda No. 886 of that group.

"While discussing the possibilities of a slotted flap control, it will be interesting to refer to some experiments carried out in 1923 at the National Physical Laboratory on tandem systems of airfoils. The work consisted of a series of tests upon a compound wing made up of a main airfoil with an auxiliary airfoil of very much smaller size arranged in close proximity to the trailing edge of the main airfoil (Fig. 259, B). These experiments, it

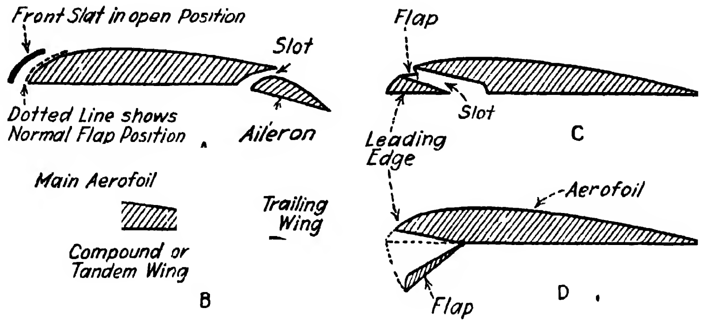


Fig. 259.—Various Devices to Facilitate Control of Airplanes at Low Speeds. A—Handley-Page Slotted Wing. B—Trailing Wing Flap. C—Slot Near Leading Edge. D—Hinged Flap Near Leading Edge.

should be pointed out, were carried out with a view to investigating the general subject of high lift compound wings and not with any considerations of control in view. The investigations showed, however, that marked high lifts could be obtained with this type of compound wing and that the increase in lift over that of a normal wing of the same total area was, under some circumstances, very much greater than similar increases with the Handley-Page type of slotted trailing flap. The possibilities of this principle being applied to the control problem, therefore, suggests itself.

"Continuing the study of control at low speeds, a limited number of experiments have been carried out in a wind tunnel with a view to so modifying the leading edge of a wing tip that a reduction in lift is accompanied by an increase in drag. Two devices were tested. One method (Fig. 259 C) consisted of a flap, arranged on the upper surface of the wing at the leading edge, which, when opened inwards, permitted the air to flow through a slot to an opening in the lower surface a short way back from the leading edge. The other method (Fig. 259 D) consisted of a flap hinged on the under surface of the wing a short way back from the leading edge. This flap is moved downwards but when in the up position contributes to the normal contour of the wing section. These devices, due to A. Fage, of the National Physical Laboratory, when tested on a model wing in a wind tunnel were found to reach their maximum effect at or about the stall and produced a rolling moment about equal to that produced by an aileron.

However, in each case the yawing moment aided the rudder and was about equal but of opposite sign to the yawing moment to be expected from an aileron.

"Further experiments carried out upon these devices showed that, when used in conjunction with ailerons, the combined control of device (a) and the aileron exceeds that of the aileron alone by approximately 13 per cent at the stall and 55 per cent at an incidence of 28 degrees. Furthermore, at the stall, the resultant yawing moment of the aileron and control device acts with the rudder, while at the higher incidence it opposes the rudder but to an extent which can easily be counteracted by movement of the rudder. In the case of device (b) combined with the aileron, the rolling moment was found to exceed that of the aileron alone by about 50 per cent at the stall and by about 120 per cent at 28 degrees incidence, while the yawing moment is with the rudder at both angles."

The problem of delaying the stall condition in airfoils and avoiding the sudden precipitation of a stall is another question which has been, to a large extent, successfully met. The nearest approach to an ideal condition in this respect has apparently been reached in the Handley-Page slotted wing.

All questions of control in airplanes, however, are entirely wrapped up in features of airfoils which directly concern the movement of the center pressure. In a modern efficient cambered wing, it is unfortunate that the movement of the center of pressure is unstable, any change in the attitude of the wing creating a new center of pressure position which further exaggerates, rather than otherwise, the tendency to change attitude. The design of an aerodynamically efficient wing with a fixed center of pressure, being impossible, therefore, other arrangements have been developed for providing this feature. The provision of the stabilizer or tailplane used in modern airplanes is one method, while swept back and washed out wings have been employed to this same end as have also normal wings with reflex trailing edges—a feature of a wing section which considerably stabilizes the center of pressure movement but greatly reduces its aerodynamic efficiency.

Handley-Page Wing.—The Handley-Page wing shown in diagram form at A, Fig. 259 represents an attempt to make a wing rather like a Venetian blind. So far, it consists of an ordinary wing with a slat across the leading edge of each wing. This slat lies flat on the edge and forms part of each wing under normal circumstances, but can be brought forward and then produces a slot between the slats and the wings. The idea is that when the wing is at a very obtuse angle in the air, the slot can be opened and, instead of the wing's losing lift, the air comes through between the slat and the wing itself and maintains the airflow so that the wing continues to lift when the airplane is at a very low speed. An advantage of this is that, in getting out of a very small field, the machine can climb at a much steeper angle; it climbs no faster and takes just as long to rise to say 100 feet, but it allows the machine to climb more nearly vertically at the same speed without covering as much ground at that speed. Hence, where an ordinary type of airplane would hit the tops of trees before it reached the necessary height, this particular type will rise over them. The same principles apply when descending. Where an ordinary machine needs a much more acute

angle to glide and so has to approach the ground at a greater distance from where it is to land, this type of wing is devised to allow the machine to come in over an obstruction such as the tops of trees and to drop to the ground comparatively near the trees; thus a very much smaller landing space can be used. All experiments show that this sort of wing works perfectly well; but the difficulty lies in the operating mechanism of the movable parts. Apparently, experiments are being made to develop a satisfactory operating mechanism which is not heavy enough to eliminate any appreciable part of the benefit of the slots. But the other mechanism, the flap wing is being used in the British Navy almost entirely on its float seaplanes and on land airplanes, because it definitely provides a much better landing-ability. One of this type, the Fairey "Flycatcher," has a speed of 145 m.p.h. when carrying all the things the Navy insists on putting on it, such as bomb racks and dock landing-hooks. Its slow-flying landing-speed is about 40 m.p.h., but it has been put down in alighting at 25 m.p.h.

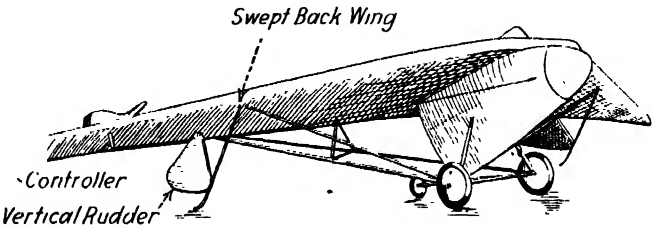


Fig. 260.—Hill "Pterodactyl" Airplane has Swept Back Wings and no Tail. This Form of Wing has a Fixed Center of Pressure.

Wing With Fixed Center of Pressure.—The possibility of attaining adequate control at and above the stall by means of the employment in the airplane of a wing with a fixed center of pressure and the possibility, therefore, of controls which serve solely as controls and not as devices for maintaining trim, has been the subject of extensive research by Captain G. T. R. Hill in England, during the past three years or so. As a result of his studies of the subject, Captain Hill has designed a tailless airplane employing a wing with the characteristic of having approximately a fixed center of pressure position regardless of the attitude of the wing up to the angle of stall. Captain Hill has employed the swept back type of wing with washed out incidence toward the tips to attain this characteristic. Control, both lateral and longitudinal is obtained by means of horizontal rudders placed at the end of the wing as shown in Fig. 260. A serious drawback in the swept back and washed out wing, from the aerodynamic standpoint, is the fact that, with the effective leverage of the wing tips small compared with that of a conventional tail, the washout must be considerable and this further decreases the aerodynamic characteristics of the wing. Captain Hill has, however, produced an extremely interesting airplane which has flown very successfully and can be controlled at angles far above the stall. The machine is known as the Pterodactyl. The landing gear consists of the conventional two wheel arrangement supplemented by a

small trailing wheel at the back of the short fuselage, which is equal in length only to the chord at the root of the wing. Small skids are carried at the base of the vertical rudder posts to keep the wing tips from contact with the ground. The wing arrangement is similar to that of the Burgess-Dunne, an experimental type built in this country about fifteen years ago.

Anti-Stalling Gear.—According to expert pilots who have had considerable experience in training student fliers, most of the accidents occur because in a contingency where the engine stops, instead of pushing the control stick forward to bring the nose down and maintain flying speed, the stick is pulled back which puts the plane at its stalling angle. The nose heavy plane is then pulled down rapidly by the heavy motor and it starts to plung earthward, a dangerous thing because the inexperienced pilot is apt to get rattled and loses control. If the airplane is not flying high, there is always the danger that control will not be recovered before it hits the

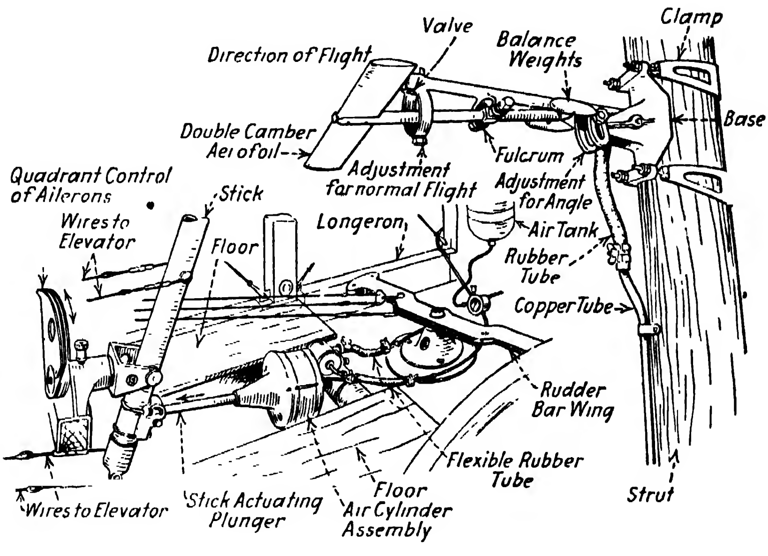


Fig. 261.—Diagrams Showing Application of Savage-Bramson Anti-Stall Gear to Airplane.

ground. Statistics have been presented to show that 75 per cent of airplane accidents are either produced by or are abetted by a stall. Any stall can be avoided if the pilot is warned before it occurs.

An anti-stalling gear has been invented by Major Jack Savage and Captain Louis Bramson of the technical staff of the Skywriting Corporation. The device gives warning to the pilot when a stalling angle is being reached. The device, which is shown at Fig. 261 is light in weight, adding but five pounds to the airplane to which it is fitted. A miniature aerofoil or wing of double-camber section is carried at one end of a pivotted lever, the other end of the lever having small counterweights to balance it. The position of this wing is controlled by the direction of airflow past it. In normal flying, the vane is carried level, but should the nose of the airplane point up so the main wings are about to assume a dangerous angle, the

windflow, impinging on the bottom of the vane produces positive pressure. The vane is raised, the lever on which it is mounted swinging on its fulcrum or pivot. The lever comes in contact with and opens a small valve connected by a relay system to an air actuated piston and plunger device which gives the control stick a sudden push forward. The angle at which the vane operates may be regulated accurately to any desired point just below the stalling angle, and when this angle is reached, the moving control stick gives the pilot a warning that he cannot fail to heed.

The one point of contact between the pilot and the plane is the control stick. While flying the pilot always has his hand on this lever and any signal given through this medium is bound to reach him immediately, in fact, in double control training ships, the control lever is employed by the instructor to transmit various signals to the pilot. A further advantage is that the anti-stall gear actually pushes the lever in the right direction and levels out the ship unless the pilot pulls against it and overcomes its power. The pilot has only to yield to the force on the control lever and the plane straightens out and gains speed. As soon as it is at a safe flying angle the correcting impulse on the control lever ceases. In tests of the device, made in England, ships were flown and an attempt made to stall them at every angle, both with the motor going full blast and with it cut off altogether, and in every instance the anti-stall gear worked perfectly. There is nothing in the device to go out of order and its light weight makes its universal adoption a practical certainty. It has been officially accepted by the British government.

Ground Run of Airplanes.—A factor of great moment that warrants careful consideration is the amount of ground run necessary for an airplane to attain its flying speed when going aloft and the distance it must travel in alighting before it will come to a stop. This is of importance in flying from small or emergency fields. The run of an airplane in landing has been materially reduced by the application of wheel brakes on latest machines. Formerly, the drag of the tail skid was largely depended on to bring an airplane to a stop but a tail skid that will exert a powerful retarding action is also one that will impose undesirable stresses on the fuselage structure and also damage the surface of the landing field. The usual procedure is to use a three-point landing. In this case, the engine is shut off or throttled way down. The pilot dives his machine at a gradual angle until near the ground, then he flattens out, moves the control stick while he still has sufficient air speed so the controls will be effective, to that point where the aerofoil is placed at or near the stalling angle, after which the machine gradually loses speed until the wheels and tail skid touch the ground simultaneously. The machine then slows down because of the aerodynamic resistance, which will vary with the velocity of the wind into which the airplane is headed and the tractive resistance, which may be greatly augmented by the use of wheel brakes instead of depending entirely on tail skid and wheel bearing friction and the resistance to rolling due to contact of flattened tires and the ground.

Before the application of wheel brakes, which seem to be a logical expedient, various methods were proposed to increase the aerodynamical resistance when landing. The landing speed may be roughly estimated at

about half of the flying speed, which means that a machine flying at 110 miles per hour will land at from 45 to 50 miles per hour. A machine weighing about 4,000 pounds, with the wings set at an angle of 16 degrees when landing, having a total resistance of 1,250 pounds will require a run of from 500 to 600 feet before the combined tractive and aerodynamical resistances will bring it to a stop. A reversible propeller would permit of running the engine at higher speeds after landing and thus develop a negative or retarding pressure. With a fixed pitch propeller, if run very slowly its positive thrust will be very slight, and if the engine can be run slowly enough, it may even exert a slight negative thrust. If the engine is completely stopped the effective blade projected area will offer some resistance, but this will be very little at low ground speeds. Wide propeller blades have a greater retarding effect than narrow blades and the high pitch screw offers less resistance than one of lesser pitch because the large blade angle permits of more easy airflow.

The suggestion has been made that panels to act as air brakes be fitted to the side of the body and opened up by the pilot when landing so they would project at right angles to the fuselage sides and bottom. The natural inference is that such plates will greatly retard the machine. On closer analysis, however, and after testing, it was found that the value of such plates was very slight because they are relatively ineffective at low ground speeds. To have any real value, such plates would have to be of such large area that they could not be easily operated nor could they be installed on the fuselage so they would not offer objectionable parasitic resistance.

A much more promising development is the use of hinged trailing flaps on the wings. An automatically operated set of wing flaps was experimented with on the early Brequet airplanes. The flaps were pulled down by rubber cords so that at low speeds the wings would have greater lift. When flying speeds were reached, the air pressure raised the flaps against the resistance of the rubber springs and they trailed in normal relation to the wings. The idea was that they would increase the wing lift in taking off and act as retarding members in landing. The automatically controlled trailing edge is not used to any extent in modern machines. Wing flaps extending over almost the entire span of the trailing edge of the wing seem to offer some advantages if they are placed under the control of the pilot. These flaps may be independent of the ailerons, or large surface ailerons may be actuated by simple mechanism so they can be moved in the same or opposite directions as the pilot wishes. Obviously, when landing they should move only in the same direction so they will act as a brake and not for producing a "roll" as would be the case if they acted in the normal manner. If the flaps had sufficient area, the pilot could set them 90 degrees, or at right angles to the wing after the machine had been placed practically at the stalling angle. The use of such flaps would reduce the air speed when landing to about 45 miles per hour in a machine that would land at 50 miles per hour without them if set at 60 degrees to the wing. After the machine had slowed down in the air and just before the wheels and tail skid touched the ground, the flaps could be dropped further to approximate right angles to the wing to act as brakes. As a result of tests,

it has been stated that by using such flaps, an airplane that would require a run of 650 to 750 feet without them could land and stop in a run of from 200 to 300 feet. The combination of such wing flaps and wheel brakes would seem to offer advantages in that the landing run would be greatly reduced. It has been stated that the use of brakes on the wheels has been avoided because they would cause the plane to nose over when the brakes were applied. This can be easily prevented by placing the landing gear so the axle center coincides with the center of gravity or comes slightly ahead of it as well as using brakes which will retard, but not lock the wheels.

To decrease the length of run necessary on the get away various suggestions have been offered. One of these, made possible by wheel brakes is to use a wheel instead of a tail skid and also mount all wheels on anti-friction bearings to reduce the tractive resistance. The tractive resistance can be materially reduced by substituting rolling for sliding friction of the tail skid. Tests show that a machine having a resistance of 500 pounds with tail skid dragging would have this reduced to 360 pounds when the tail was supported by a wheeled gear. The pilot should, therefore, get the tail skid off of the ground as soon as he can and thus remove considerable tractive resistance. If the center of gravity is not too far back of the wheel axle, this should be possible almost as quickly as the engine is speeded up and the air thrown back by the tractor screw strikes the hanging elevators. The subsequent run, after the tail is raised should be at a relatively small angle of incidence until flying speed is obtained. A variable pitch propeller will materially assist in securing a short starting run or "get away" because the pitch can be made small on the ground, permitting the engine to quickly attain its full power and r.p.m. In this case, it would act just as the low gear does in an automobile. After the plane had left the ground, and when the resistance produced by climbing had been reduced to that of level flight, the pitch angle of the blades could be increased and engine r.p.m. slowed down. In this case comparison can be made with an automobile running in high. A skilled pilot can usually get away in a shorter run than he needs when landing. In a machine needing 750 feet run to stop when landing, the take-off is about 500 feet. These values are for airplanes without any devices to facilitate taking-off or to assist in retarding the speed when landings are effected.

Instruments for Navigating Airplanes.—A typical cockpit of an early type airplane, showing the various instruments comprising the control system, is shown at Fig. 262. The various indicating instruments which assist the pilot in controlling the machine are shown. An air pressure or speed indicator shows the air speed of the machine. An altimeter, which is a form of aneroid barometer, indicates the height of the machine above the ground. A tachometer is employed to show if the engine is turning at the proper speed. The clock indicates time and is very useful when used in connection with a speed indicator in determining distance travelled. Two pressure gauges are provided, one indicates the oil pressure, the other one the pressure of the air in the fuel feed system. The switch is used to establish and interrupt ignition. An ammeter is mounted on the switch to show if the generator is charging the battery, when that system of ignition is used. When magnetos are used for ignition, the ammeter is not

required unless an electric starting motor system is used. When fuel is by gravity feed, no air pressure indicator is needed, as the fuel is moved by gravity, which needs no gauge. In addition to the instruments shown, airplanes may be provided with an earth inductor compass as well as a magnetic compass. A turn pitch and bank indicator is of great value as is a rate of climb indicator. An air distance recorder is valuable for supplementing the air speed indicator. A drift and speed indicator is a useful navigation instrument. A thermometer is provided to indicate the temperature of the jacket water when the water-cooled type of engine is used as power. A more extended description of various instruments will be given in a following chapter. Throttle and spark levers (not shown) are utilized to regulate the engine speed. When the pilot is to make a trip of any magnitude a compass is provided.

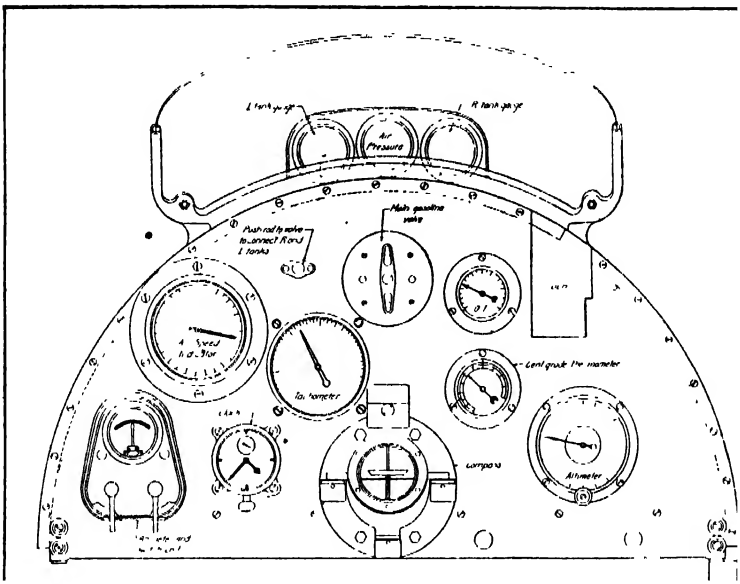


Fig. 262.—Instrument Board of Military Airplane Showing Arrangement of Instruments Used in Connection with Plane and Liberty Engine Control.

Suggestions for the Student in Flying.—To begin with, the rules governing the handling of a plane that can be put down on paper are very few, for three chief reasons: First, that no two machines handle alike; second, that no two pilots fly alike; third, that atmospheric conditions change so often. These so-called atmospheric conditions are the things that are most difficult to overcome; namely, hot and cold currents of air or upward and downward currents of air which have a natural tendency to take the plane to a certain extent in their same direction. We ofttimes hear the student speak of an air "pocket." There is no such thing as an air "pocket." The so-called air "pocket" is merely a downward current of air which has, as above stated, a natural tendency to take the plane in the same general direction.

The things the student learns first are the things he should never forget. There are two things the student should learn first of all, i.e., always keep flying speed, and always keep in mind what position you are in relative to the wind. Without these two things in mind you cannot properly, or safely, handle your plane—speed, especially, being the greatest factor which is obtained and maintained from two sources, namely, propeller thrust and gliding. In case your primary source of speed ceases with either a known or unknown reason, the immediate thing to do is to nose the plane into a glide, sufficient to maintain flying speed. Don't worry about what the trouble is before so doing, or your troubles will pile up, and so will the machine.

Before starting on a flight look over your machine in a general way to check up on the inspection given by the mechanics charged with its maintenance. Do not take anybody's word that there is enough gasoline, oil and water; check these points yourself. Examine principal control wires and move rudder bar and control stick or wheel in all directions to make sure the control members function as they should.

Run Motor Slowly to Warm It.—Let motor run idly until it is warm and oil is circulating properly as indicated by oil pressure gauge. Test engine for revolutions per minute as indicated on the tachometer, but never race the engine for more than a few seconds in determining this. Be sure the wheels are chocked or blocked or that the wings are held by several men to prevent forward motion of the machine when the engine is speeded up. Never run an airplane engine unnecessarily when on the ground, as this reduces the flying time or the service the engine will give in the air. Special attention should be given to the way high compression engines are run on the ground. These should never be run at full throttle on account of danger of preignition; in fact, any excessive running of such engines will result in their quick deterioration.

As soon as you feel sure that the power plant is functioning properly and that your controls are in good condition, you should taxi to a smooth level spot, with hard, dry ground or short grass that will provide a runway of several hundred yards in the direction the wind is blowing. Avoid soft or sandy ground or spaces having hummocks or long grass. If in doubt about the nature of the ground have an assistant at each lower wing tip. Watch carefully for the direction of the wind and start off with the full power directly into the wind. The tendency of the machine to turn to the left due to the propeller blast striking the left side of the fin more than the right side is counteracted by right rudder.

How to Take-Off.—When the machine has attained fair speed, which it will do at about 100 to 200 feet, the tail should be raised by tilting the elevator flaps down by pushing the stick or control bridge forward slightly. This keeps the machine from leaving the ground until it reaches its proper flying speed. When this point is reached, which varies with the construction of the plane and velocity of the wind it is heading into, usually at speeds of 50 to 60 miles per hour, then move the control lever by pulling it back slowly, taking care that ailerons are in neutral position until the machine is well up in the air.

Take-off at high speed is always best as the plane has attained a certain

momentum that insures a safe landing if the power should fail suddenly. For the same reason, the take-off should be at a good climbing angle; a machine should never be "zoomed" or made to jump into the air by a too rapid movement of the elevator flaps. If a machine of average power loading is made to climb at an abrupt angle, the plane is apt to stall and sideslip to the ground. Zooming close to the ground is particularly dangerous if an engine is not developing full power or if it should fail suddenly. Stalling is a part of acrobatic flying and is not dangerous if carried on by a capable pilot at sufficient height from the ground. Remember that engine failure close to the ground nearly always results in a crash if it occurs when taking off too slowly or at a sharp angle.

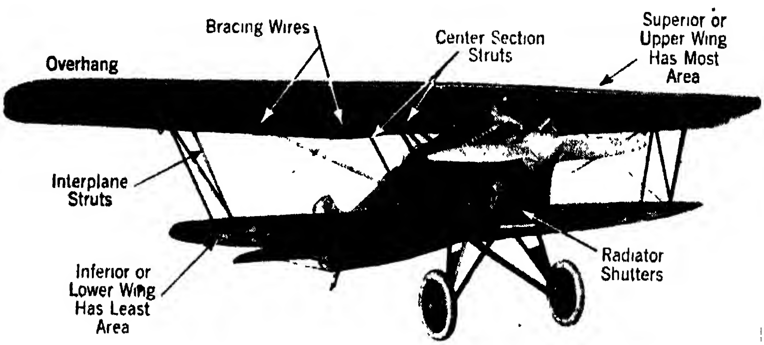


Fig. 263.—The Boeing Sesqui-Wing PW 9 Biplane, a Type Adapted for High Speed Pursuit Work.

How to Attain Altitude and Handle Machine.—As soon as the plane is under way it should be driven in a straight line and at a gradual angle of climb until a safe altitude is reached, which should be between 800 and 1,000 feet. It is stated that a high-speed low angle climb is much better than a slower large angle climb. The angle of climb, of course, depends on the power available and resistance of the airplane parts. A high-powered machine of little resistance can climb at angles greatly in excess of those possible with the usual training type of airplane.

A height of at least 1,000 feet should be attained before a turn should be attempted by any but the most experienced pilots. A point to bear in mind at all times is the possibility of the airplane power plant stopping, so the pilot must keep a safe landing place within gliding distance at all times. If one is climbing and it is desired to make a rather short turn, the machine is nosed over until it is flying level in order to keep the speed high. Simultaneously, the vertical rudder and ailerons are operated so the turn is made in the desired direction and banking proportional to the speed and radius of the turn.

A turn of wide radius with a minimum of bank is better for the novice than turns of short radius which require steep banking. If a short turn is attempted and banking is not properly done, the machine may skid if the bank is not sufficient and sideslip if the bank is excessive and speed too slow. Either of these extremes is very dangerous, especially if it occurs

close to the ground. A high angle of climb should be avoided on account of danger from "stalling," which can only take place with safety at considerable distance from the ground. It is said that the modern airplane of good design has considerable inherent stability and it is better to be easy with the controls than to work them too quickly. Owing to the spread of an airplane immediate response to controls is not always obtained, a brief interval is required to have the plane answer. The slower and larger the airplane is, the more time is needed for controlling it. High speed, single-seater scouts are very responsive to controls, while bombing planes are not so maneuverable. The controls should not be jerked, but should be firmly and smoothly handled. An expert pilot soon learns the feel of his ship and operates controls smoothly while the novice commonly overcontrols through sudden movements continued too long.

When a safe altitude is reached the pilot need have no anxiety if a landing field is within gliding distance. The gliding possibilities of a machine depend on its design primarily; most machines have a gliding angle of 7 or 8 to 1, which means that the plane will glide a distance 7 to 8 times its vertical height. The direction of the wind has much to do with gliding distance and speed. Naturally, the possible distance of glide without power will be less when the machine is going against the wind than if it is with the wind.

When flying in a side wind it is necessary to fly at an angle in order to proceed in a straight line. This angle depends on the wind pressure and is necessary to effect the drift of the machine. Drift must also be considered in making turns. It is always best to nose down when turning in a cross wind in order to make sure one has the proper flying speed. While the air speed of a machine is always the same, the speed with relation to the ground changes with the wind velocity. A machine that would attain a speed of 70 miles per hour, relative to the ground in still air, will fly at 100 miles with a 30-mile wind back of it and move but 40 miles relative to some fixed point on the ground if its forward motion was opposed by the same wind. Air speed is therefore radically different than ground speed.

Precautions When Landing.—In landing, certain precautions must be observed. When you feel you have approached your landing place sufficiently, shut off the engine, or better, throttle it down if there is any doubt about reaching the field on a normal glide. Always make a landing into the wind, as this will exert a braking action and bring the ship to a stop quicker. Never land in a cross wind if it can be avoided. If it is found that the ship is too close to the field to make a long, easy glide, a series of wide S turns can be made to reduce speed as well as altitude. Do not attempt to spiral into a field unless you are confident of your ability to execute the maneuver properly. If the pilot has overshot the mark to any extent, it is better to make a wide circle and make another try at the field, starting your glide at the proper distance. The long, straight glide into the wind is the best way for anyone to make a landing, especially the novice, as it gives one a better chance to judge both wind and distance.

Danger in Stalling.—One of the most serious mistakes the novice flyer is apt to make is gliding at too flat an angle, and the reason this is dangerous is that the loss of flying speed will result in the plane settling instead

of gliding as it should. It should be remembered that unless flying speed is attained and maintained at all times, that the controls become inactive to considerable extent. The proportions of the ailerons and elevator flaps are based at a definite air resistance according to a speed which is but slightly less than the normal flying speed of the machine. It is necessary to have a pronounced air pressure on all controls if they are to be effective, and in order to have the airplane responsive to movements of the control planes, it is necessary to maintain flying speed either by use of the motor and propeller thrusts, or by a steep glide. In gliding, when the field is reached and the machine is 50 or 60 feet from the ground, it is desirable to begin "levelling off," but the final "levelling off" should not be done until the machine has glided to a distance of approximately 6 or 7 feet from the ground. The motor is shut off and at this point the airplane is moving forward, neither rising nor falling until its flying speed stops; thus it will sink to the ground gradually as the angle of attack of the wings is increased to bring the lift up to the point where it will carry the weight of the machine at a lessened speed. When the airplane is in the correct position for landing at its lowest flying speed, the tail skid and wheels of the machine should be just grazing the ground. Always pick as smooth and level a piece of ground as possible when making a landing, as, if the ground is very soft or if there are hummocks or ditches, the machine is very likely to "nose over." This, of course, will result in breakage of the propeller and impose considerable strain on parts of the airplane, even if it does not result more seriously.

Control in Making Turns.—The student aviator will perceive a pronounced tendency of an airplane to "nose down" when turning right hand and to climb when turning left hand. The last named condition is not as noticeable as the first named. This action is said to be due to the gyroscopic force of the propeller and must be met by the elevators to keep the machine level. An important point to remember is that in banks of from 20 degrees the functions of the rudder and elevators interchange, the latter really become rudders to direct the machine in a horizontal flight, while the vertical rudder, which normally directs its motion to the right or left, becomes an elevator to raise the machine up and down. The pilot must bear this in mind and when the machine is descending at a pronounced angle in action, all horizontal balance must be made by the vertical rudder and not by the elevators.

Perhaps the most common cause of airplane accidents, and one that is ever present when inexperienced pilots are handling the machine, is what is termed as "the tail spin" or "spinning nose dive." The tail spin is not dangerous to an experienced pilot if there is sufficient altitude to correct the machine's tendency to fall. In fact, in acrobatic flying, tail spins are very common and are used as a method of losing altitude. A tail spin is usually started by excessive banking with too much rudder, and the nose end of the machine falling, due to stalling or engine faults. Under these circumstances the ailerons and elevators are useless, for the air does not strike their under surface, but their edges. The best control method to counteract a tail spin is to set the control lever regulating on the ailerons and elevator in a vertical position and to put all possible rudder on in the

direction opposite to that in which you are spinning, even though both feet must be used on one side of the rudder bar to exert the proper pressure. The rudder should be held in that position and the motor run on full throttle to supply all the possible air pressure. If there is sufficient altitude the machine will gradually straighten itself out and as soon as you realize that the rudder is functioning properly the same degree of control may be regained by using the elevators and ailerons in order to bring the machine to its proper flying position.

Flying Learned Only by Practice.—The point that must be borne in mind by all students of aviation is that it is not possible to learn to fly by reading a book, any more than it is to learn to swim or to ride a bicycle by the same method. A certain cooperation of the senses to produce the required sense of balance is necessary and only practice under the tutelage of a competent pilot will enable the aviator to fly. There have been exceptional cases of when men have taught themselves to fly, as the early experiences of the Wright brothers and of Glenn Curtiss demonstrated. At the same time, a number of pioneers who were their contemporaries gave up their lives in attempting to solve the same problems. The control of a machine in the air is not difficult as the pilot soon learns the necessary movements to have the plane recover its balance, or to nose up or down. The landings are the most difficult thing as in making them it is only possible to make good ones by a combination of good judgment of distance and speed that comes naturally from considerable practice. Many instruments and indicators have been devised so airplanes of today can be piloted by people that could not operate the earlier type airplanes.

The following list of precautions are published by the Curtiss Aeroplane and Motor Corporation for the benefit of pilots using their machines, and as they are easily memorized and applied to all types they can be committed to memory by any prospective pilot to good advantage.

Important Hints

1. Remember that "A stitch in time saves nine."
2. Always inspect the motor thoroughly before starting.
3. Always have plenty of oil, water and gasoline before trying to start; all three are vital.
4. See that the radiator is *full* of water before starting.
5. Keep oil and gasoline clean, and free from water.
6. Oil all exposed working parts daily.
7. Be sure to retard magneto before starting; otherwise a serious accident may result.
8. Turn on switch before trying to start.
9. Start the motor with the throttle only part way open.
10. Run the motor idle for only short periods; it is wasteful and harmful to run idle too long.
11. Watch the lubrication constantly, it is most essential.
12. Remember that the propeller is the business end of the motor; treat it with profound respect when it is in motion.
13. When the motor is hot allow it to idle a few minutes at low speed

before turning off the switch. This insures the forced circulation of the cooling water until the cylinder walls have cooled considerably and also allows the valves to cool, preventing possible warping.

14. Avoid that destructive disease known as "tinkeritis"; when the motor is working satisfactorily, leave it alone.

15. Be sure to inspect daily all bolts and nuts. Keep them well tightened.

16. Stop the motor instantly upon detecting a knock, a grind, or other noise foreign to perfect operation. It may mean the difference between saving or ruining the motor.

Fuel Economy in Flying.—Fuel-consumption in flight, is dependent on three main factors, namely, the aerodynamic efficiency of the airplane, the thermal efficiency of the engine and the efficiency of navigation, which entails a study of the most advantageous height, speed and direction of flight under any conditions of wind. It is stated that distinct advances have been made in the direction of fuel economy in flight since the war period but that even now the weight of fuel carried in a commercial machine operating over the comparatively short London-Paris route of 230 miles and capable of a cruising speed of 100 m.p.h. is approximately half the full paying load carried, so that a reduction of the fuel load by 40 per cent, which is claimed to be by no means outside the range of possibilities, would increase the paying load by 20 per cent, other things being equal. The problem of fuel economy in flight may be divided into two parts: (*a*) the principles governing the most economical use of an airplane in flight, having regard to weather conditions, and (*b*) the principles underlying the design of airplanes to secure the maximum efficiency of operation.

Terms of Stability Theory

damping factor—The factor $e^{-\lambda t}$ in the equation of damped harmonic motion

$$s = Ae^{-\lambda t} \sin pt.$$

divergence—A motion in which, after a disturbance from equilibrium, the body departs continuously, with oscillations, from its original state of motion.

logarithmic decrement—The natural logarithm of the ratio of two successive amplitudes in a damped harmonic motion. It is equal to the product λT where λ is the coefficient appearing in the damping factor of damped harmonic motion and T is the period of the motion.

period—The time taken for a complete oscillation.

phugoid oscillation—A long-period oscillation characteristic of the disturbed longitudinal motion of an aircraft. This is referred to when it is said that an aircraft "hunts."

resistance derivatives—Quantities expressing the variation of the forces and moments on aircraft due to disturbance of steady motion. They form the experimental basis of the theory of stability, and from them the periods and damping factors of aircraft can be calculated. In the general case, there are 18 translatory and 18 rotary derivatives.

rotary—Resistance derivatives expressing the variation of moments and forces due to small changes in the rotational velocities of the aircraft.

translatory—Resistance derivatives expressing the variation of moments and forces due to small changes in the translational velocities of the aircraft.

righting moment (or restoring moment)—A moment which tends to restore an aircraft to its previous attitude after any small rotational displacement.

stability—That property of a body which causes it, when disturbed from a condition of equilibrium or steady motion, to develop forces or moments which tend to restore the body to its original condition.

automatic—Stability dependent upon movable control surfaces automatically operated by mechanical means.

inherent—Stability of an aircraft due solely to the disposition and arrangement of its fixed parts; i.e., that property which causes it, when disturbed, to return to its normal attitude of flight without the use of controls or the interposition of any mechanical devices.

static—Stability of such a character that, if the airplane is displaced slightly from its normal attitude by rotation about an axis through its center of gravity (as may be done in wind tunnel experiments), moments come into play which tend to return the airplane toward its original attitude.

dynamic—Stability of such a character that, if the airplane is displaced from steady motion in flight, it tends to return to that steady state of motion, the oscillations due to restoring moments being damped out.

In a general way, the difference between static stability and dynamic stability is that the former depends on restoring moments alone, while the latter includes the action of damping factors.

longitudinal—Stability with reference to disturbances in the plane of symmetry; i.e., disturbances involving pitching and variation of the longitudinal and normal velocities.

directional—Stability with reference to rotations about the normal axis; i.e., an airplane possesses directional stability in its simplest form if a restoring moment comes into action when it is given a small angle of yaw. Owing to symmetry, directional stability is closely associated with lateral stability.

lateral—Stability with reference to disturbances involving rolling, yawing, or sideslipping; i.e., disturbances in which the position of the plane of symmetry of the aircraft is affected.

spiral instability—A type of instability inherent in certain airplanes which becomes evident when the airplane, as a result of a yaw, assumes too great a bank and sideslips; the bank continues to increase and the radius of the turn to decrease.

stable oscillation—An oscillation whose amplitude does not increase.

unstable oscillation—An oscillation whose amplitude increases continuously until an attitude is reached from which there is no tendency to return toward the original attitude, the motion becoming a steady divergence.

Operation and Maneuvers

bank—To incline an airplane laterally, i.e., to rotate it about its longitudinal axis. Right-bank is to incline the airplane with the right wing down.

Also used as a noun to describe the position of an airplane when its lateral axis is inclined to the horizontal.

ceiling:

absolute—The maximum height above sea level at which a given airplane would be able to maintain horizontal flight, assuming standard air conditions.

service—The height above sea level, assuming standard air conditions, at which a given airplane ceases to be able to rise at a rate higher than a small specified one (100 feet per minute in the United States and England). This specified rate may be different in different countries.

dive—A steep descent, with or without power, in which the air speed is greater than the maximum speed in horizontal flight.

glide—A descent with reference to the air at a normal angle of attack and without engine power sufficient for level flight in still air, the propeller thrust being replaced by a component of gravity along the line of flight. Also used as verb.

nose-heavy—The condition of an airplane in normal flight when the distribution of forces is such that, if the longitudinal controls were released, the nose would drop.

pancake, to—To level off an airplane at a greater altitude than normal in a landing, thus causing it to stall and to descend on a steeply inclined path with the wings at a very large angle of attack and without appreciable bank.

power loading—The gross weight of an airplane, fully loaded, divided by the normal brake horsepower of the engine computed for air of standard density, unless otherwise stated.

range:

at economic speed—The maximum distance a given aircraft can cover while cruising at the most economical speed and altitude at all stages of the flight.

at full speed—The maximum distance a given aircraft can cover at full speed at sea level.

reverse turn—A rapid maneuver to reverse the direction of flight of an airplane, made by a half loop and half roll.

roll—A maneuver in which a complete revolution about the longitudinal axis is made, the horizontal direction of flight being approximately maintained.

sideslipping—Flight in which the lateral axis is inclined and the airplane has a component of velocity in the direction of the lower end of the lateral axis. When it occurs in connection with a turn, it is the opposite of skidding (q. v.).

skidding—Sliding sidewise away from the center of curvature when turning. It is usually caused by banking insufficiently, and is the opposite of sideslipping (q. v.).

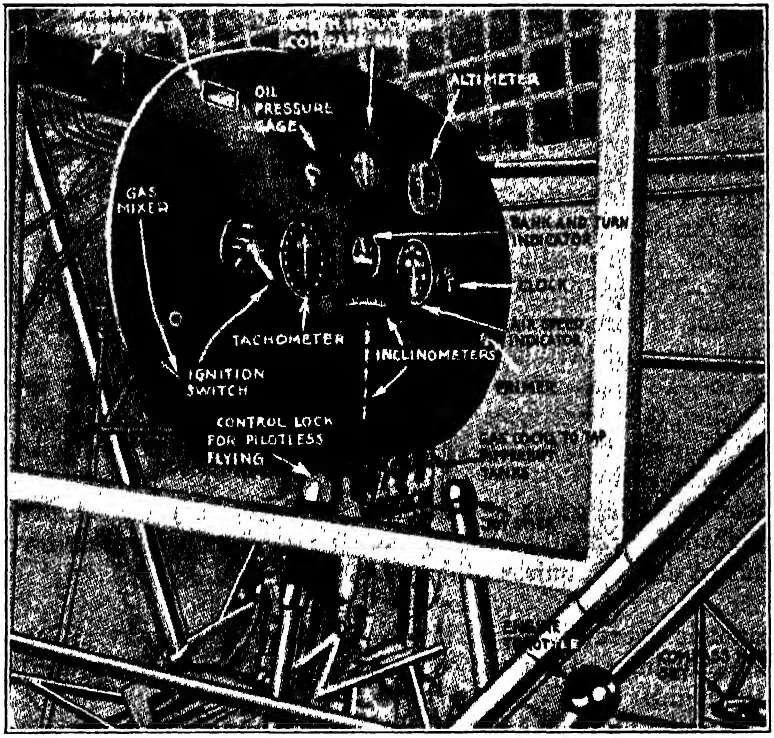
skywriting—The act of emitting from an aircraft a trail of smoke or other visible substance, the flight of the aircraft being so directed as to cause the trail to assume the form of letters or symbols.

soar—To perform sustained free flight without self-propulsion; it is called "up-current soaring" if performed in ascending air; "dynamic soaring" in other cases.

speed:

critical—The lowest speed of an aircraft at which control can be maintained.

economic—The speed at which the fuel-consumption per unit of distance covered in still air is a minimum.



Instrument Board of Ryan NYP Monoplane Used by Captain Charles Lindbergh.

landing—The minimum speed at which an airplane can maintain itself in level flight and still be under adequate control.

minimum—The lowest steady speed which can be maintained by an airplane in level flight at an altitude large in comparison with the dimensions of the wings, with any throttle setting whatever.

spin—A maneuver consisting of a combination of roll and yaw, with the longitudinal axis of the airplane inclined steeply downward. The airplane descends in a helix of large pitch and very small radius, the upper side of the airplane being on the inside of the helix, and the angle of attack on the inner wing being maintained at an extremely large value.

spiral—A maneuver in which an airplane descends in a helix of small pitch and large radius, the angle of attack being within the normal range of flight angles.

stall—The condition of an airplane when from any cause it has lost the air speed necessary for support or control.

tail-heavy—In a heavier-than-air craft the condition in which in normal flight, the tail sinks if the longitudinal control is released, i.e., the condition in which the pilot has to exert a push on the control stick to keep the given attitude.

tail slide—The backward and downward motion, tail first, which certain airplanes may be made to take momentarily after having been brought into a stalling position by a steep climb.

taxi—To run an airplane over the ground or a seaplane on the surface of water under its own power.

warp—To change the form of a wing by twisting it. Warping is sometimes used to maintain the lateral equilibrium of an airplane.

wing-heavy—The condition of an airplane in which (in normal flight) there is a tendency for the right (or left) wing to drop, if the lateral control is released, i.e., the condition in which the pilot has to exert a lateral force on the control stick to keep the lateral axis horizontal.

zoom—To climb for a short time at an angle greater than that which can be maintained in steady flight, the airplane being carried upward at the expense of its kinetic energy. This term is sometimes used as a noun to denote any sudden increase in the upward slope of the flight path.

QUESTIONS FOR REVIEW

1. Outline main factors regulating airpiane equilibrium and stability.
2. What is the point called in an airplane where the forces centered?
3. What is the difference between the "center of pressure" and the "center of gravity"?
4. Why are relatively small control surfaces effective in balancing or steering an airplane?
5. Compare wing warping and ailerons for controlling lateral balance. Which method is best?
6. Compare "stick" and "Dep" control systems.
7. Why is an airplane "banked" in turning?
8. Describe "balanced control surfaces" and outline principal methods of balancing.
9. What is the influence of rear stabilizer placing on airplane balance?
10. Name factors controlling ground run of airplanes in starting and alighting.

CHAPTER XIII

UNCRATING, SETTING UP AND ALIGNING AIRPLANE

How to Unpack a Curtiss JN-4 Biplane—How Parts are Packed—Examination of Parts before Assembly—Assembling Landing Gear to Fuselage—Center Section Panel Assembly—Main Panel Assembly—Adjustment for Dihedral—Three Methods of Checking Dihedral—Checking Stagger—Wash-in and Wash-out—Empennage or Tail Assembly—Landing Gear—Horizontal Stabilizer—Vertical Stabilizer —Elevators—Rudder—Aileron Adjustment—Rudder Control Adjustment—Elevator Control Adjustment—General Instructions—Checking Alignment of Wings and Fuselage—String and Straightedge Method of Aligning Fuselage—General Rules for Assembly and Alignment—Typical Alignment Drawing Explained—Handling Airplanes on the Ground.

While it is possible to assemble an airplane by many methods and in various sequences, it will expedite and safeguard many possible errors to follow closely the chronological order established by such experience that has been gained by the several government schools during the past, and now adopted as the standard by most manufacturers. The Curtiss training biplane is taken as an example because it is a well-known pre-war type, and widely used in all parts of America and in Canada. Other types of airplanes will need different methods, depending upon their design but as instructions are usually furnished by their makers, the routine procedure can be varied as conditions make necessary. The procedure for any biplane will be practically the same as for the Curtiss JN4, which is one of the best known and most widely used of all wartime planes by civilians. Packing an airplane for shipment can be easily accomplished by reversing the order of operations given for unpacking, with such modifications as will suggest themselves to the mechanics doing the work.

How to Unpack a Curtiss Biplane

1. Fuselage.—The fuselage of the JNs comes packed in special cases to prevent damage occurring while unpacking. To assure success the following instructions should be followed explicitly.

2. The packing case should always be kept on a flat surface to prevent warping the body of the machine. To prevent the necessity of turning the fuselage over and to prevent shifting of the motor, the case should always be kept with "Top" uppermost. The top may be easily recognized by its construction and by the mark.

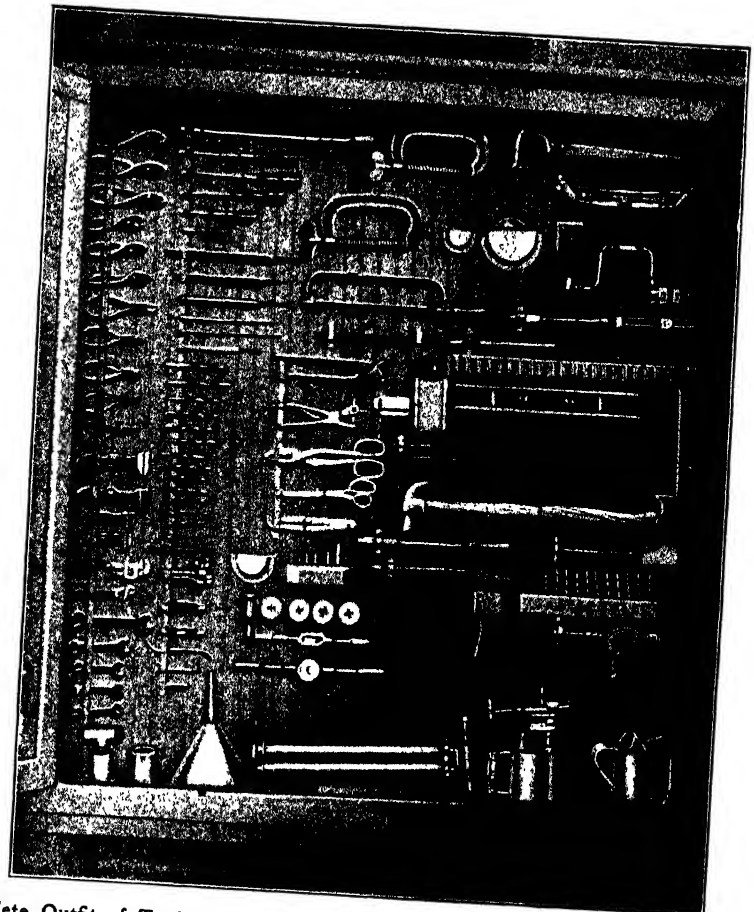
3. In opening the case use a nail puller—never an axe or saw.

4. In taking off the top, draw out all the nails that are driven through the sides and ends. This will allow the top to be taken off whole. Pull nails from, and remove cross braces to free propeller, which can then be lifted from case.

5. The next step is to remove the side marked "Front," and then the ends. All metal strips should be taken off first. The bottom and back side are left in place.

6. The fuselage should next be *lifted* out, which will leave the landing gear, wheels, etc., easily accessible.

7. The instructions for the fuselage should be followed in removing the panels. The side marked "Top" should be first removed, being careful to pull all the nails, then remove the nails from blocks that hold the cross pieces in place. When each set of cross pieces has been taken out the panels may be removed from the box.



Complete Outfit of Tools for Erecting and Taking Care of Airplanes. The Outfit Shown is Adequate Equipment for a Crew of Six Men.

How Parts Are Packed.—The major parts of the JN4 are packed in two cases, which may be designated by their contents as follows:

1. Fuselage.
2. Panels.

(1) The fuselage contains the motor set in place, with the instrument board and instruments all connected up; with the carburetor control and adjustment; throttle controls; with magneto cut-out switches all connected

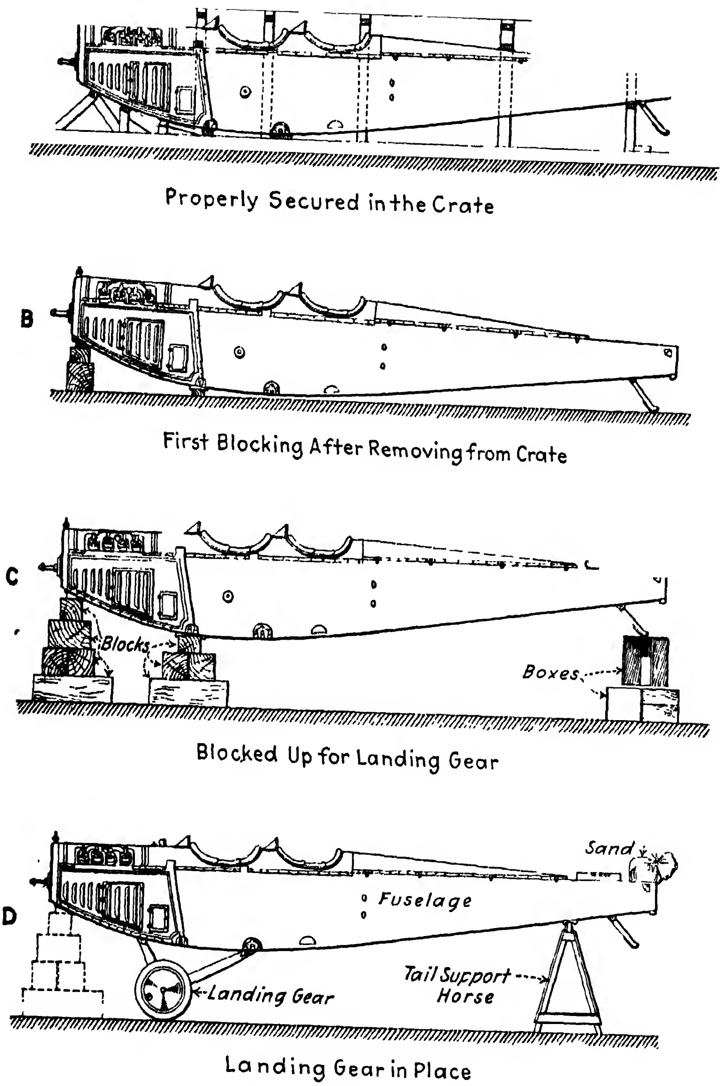


Fig. 264.—Showing Steps in Uncrating Airplane Fuselage and Blocking it Up to Take Landing Gear. A—Fuselage in Crate. B—First Blocking. C—Blocked Up for Landing Gear. D—Landing Gear in Place, Blocks Removed.

up and ready for operation, and with the tail skid in place. The control sticks are in their proper place. Around the seat-rails will be found the leads connected to the segment of the stick control for operating the ailerons, while the leads for controlling the elevators will be found at-

tached to the control walking beams, with ends passed through the fair-leads and coiled up in the fuselage back of the seat of the pilot. The rudder control wires are fastened to the foot control bar, and lead to the rear end of the fuselage cover, coiled up ready for leading through the fuselage for fastening to the rudder.

The landing gear, with cross stay wires connected up loosely, is completely assembled in this case. The landing gear wheels, propeller and exhaust equipment are also in this box.

(2) The panels with sockets and hinges all attached are in the panel box. The transverse and longitudinal wires are attached to the under side of the upper wing, coiled up and ready for attaching to the lower wing. The aileron control pulleys are in place on the under side of the upper wing; the aileron control cables have been passed through these pulleys and are coiled up with shackles and pin at one end for attaching to the control pylons of the aileron, and turnbuckles at the other end to be attached to

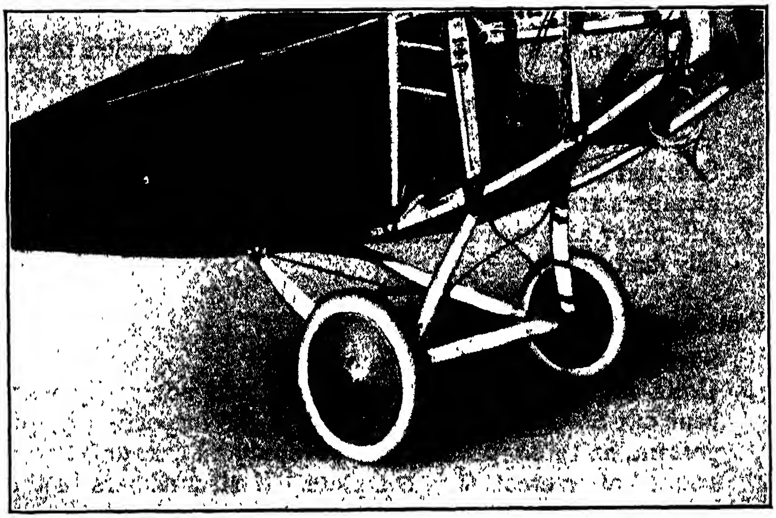


Fig. 265.—Landing Gear Installed on Fuselage of Training Biplane.

the lead which comes from the stick control segment and through the side of the fuselage. This same panel case also contains the elevators and rudder with control pylons removed. This case contains all the control pylons for the ailerons, elevators and rudder. In this box also are contained the panel struts and engine section struts. The details of contents are given in the packing lists, marked "Panels."

When using a sling in lifting box containing the fuselage, care should be taken that the center of the lift comes somewhat ahead of the center of the box toward the motor end. This point can be quickly determined by trial, by lifting the bridle until the box rides level.

Examination of Parts Before Assembly.—With each fuselage box is sent a set of assembly drawings. These drawings should be studied carefully before commencing erection of machine. Each part should be identified by comparison with the erection prints as it is taken from the box. Each part

which is packed separately from the unit of which it is a member has its identification number attached. All such units should be assembled before the machine proper is started on. If the instructions for unpacking are followed closely the danger of injury to members will be greatly lessened. The entire machine has been inspected and checked before shipment, but before setting up is attempted, go over the machine thoroughly and note the following:

A. Fuselage.

1. That no members are bent or damaged.
2. That the wires are in good condition. The fuselage trussing is shipped trued up, and hard wires should be taut. Safety wire on all turnbuckles on these wires should be intact.
3. No bolts on the trussing fittings should be loose or unlocked.
4. Be sure that the flexible cable leads are not kinked or the cable worked open. These leads will be found coiled up out of the way and should be left there till needed.
5. Make sure that no bolts or locking devices needed to erect the machine are missing. These bolts have been either put in place on the fitting to which they belong or will be found in a small bag in the front part of the fuselage case.
6. See that no exposed fittings necessary for alignment to other members are damaged or bent.
7. All motor and instrument connections should be tight and properly made.

B. Panels and Tail Surfaces.

8. Surfaces must not be broken or torn.
9. Units should be comparatively tight and not easily warped or bent out of alignment. This part of the inspection is quite important, as these members are covered and cannot be readily inspected after erection is complete. If all members in the plane of the trussing are in alignment and not damaged, overstressed, or slackened, a considerable degree of rigidity may be expected.
10. All fittings on these surfaces should be tight and all bolts properly locked.
11. No flying, landing, or cross-bracing cables should be kinked, or the cable strands loosened.

C. General.

12. Check off on the packing sheets the remaining members necessary to complete the setting up. Make sure that all are present.

Assembling Landing Gear to Fuselage.—To assemble the landing gear, mount the wheels onto the axle and bolt in place, the fuselage is then elevated, either by tackle or by shims and blocking. If block and tackle are used, pass a line under the engine bed supports just to the rear of the radiator. To this line the hook of the block should be attached. Lifting device must not be attached to any other part, as there is danger of dam-

aging or crushing. With the fuselage now resting on blocking, location of same being under the fuselage, at a vertical member of the fuselage side trussing, just ahead of the tail skid, lift the front end until the lower longeron clips for attachment of landing gear struts clear the landing gear. These clips may be easily found on inspection. The short bolts, with lock washers, nuts and cotters are found in the clips attached to the bottom longerons. With the lock washers under the heads of the bolts, and when the clips on the longerons line up with the clips on the ends of the landing gear, the bolts are passed down through the holes thus aligned. This facilitates assembling and inspection by placing the bolts on the down side. The castellated nuts are then put on the bolts and drawn tight until the drilled hole on the bolt is visible through the castle of the nut. The cotter pin is then inserted and the leaves spread back in two directions, which locks the nut in place. When the landing gear has been completely assembled to the fuselage, the tail of the machine should be elevated by a horse and blocking under the tail until the top longeron is level. Use a spirit level to determine this.

The other method that may be used in raising the front end of the fuselage to assemble the landing gear is as follows: Take out the blocking and front flooring of the shipping case from under the fore part of the fuselage. Insert a block under the bottom longerons at a point ahead of the point on which the fuselage is resting in the case. This block should be aligned under the vertical strut as shown in Fig. 264. The floor to the rear of the block may now be taken out. The nose of the machine is elevated by lowering the tail, using the above mentioned block as a fulcrum. The nose of the machine should next be blocked up, being sure to place blocking under radiator bracket and not under radiator. Now lift the tail of the machine and this nose blocking will serve as a fulcrum and the fuselage at station 4 will clear the blocking at that point. Again block up under station 4 with wedges until block is tight against lower longeron. Again elevate the nose of the machine by depressing the tail. The nose blocking will now need to be increased. Thus, by alternately changing the fulcrum point and increasing the blocking, the nose will be finally raised to the point where the landing gear may be assembled to the fuselage. The appearance with landing gear installed is shown at Fig. 264 D and at Fig. 265.

Center Section Panel Assembly.—The engine, or center section panel, must be erected before the main panels can be connected to the fuselage. The center section struts are first placed in their sockets on the upper longerons. These posts will be found in the panel box. The forward posts are approximately held in place by the flexible wire lines, which will be found coiled up and fastened to the under side of the cowl in the motor compartment. The rear struts are approximately held in place by the flexible wire lines leading from the lower longeron at station 7, and will be found tied to the control stick in the forward cockpit. The center panel is now mounted on the struts after the front transverse bracing between the posts is trued up approximately. The engine section panel posts and wires may then be trued up before further erection. To obtain this condition all similar wires are adjusted to the same length.

Main Panels Assembly.—There are two methods of assembling the main panels to the machine. The panels, struts and wires may be assembled before attaching to the fuselage, or assemble the upper panel to the center section and then complete assembly. The first method is considered the better, as it permits of setting the main panels at the correct stagger and dihedral, requiring less subsequent adjustment than the other method.

First Method. All the main struts are marked with a number. The method used is as follows: Starting with post No. 1, which is the outer post on the left-hand side of the pilot as he faces the direction of travel, the front posts are numbered to No. 4, Nos. 1 and 2 being on the left side, and Nos. 3 and 4 being on the right. The rear posts are similarly numbered, from 5 to 8, Nos. 5 and 6 being on the left and Nos. 7 and 8 on the right. This does not include the center section struts. (See A, Fig. 267.)

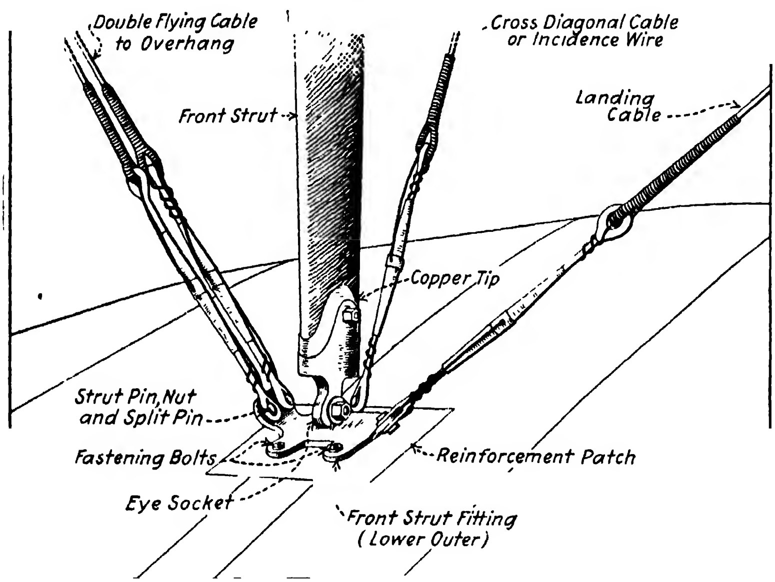


Fig. 266.—Lower End of Interplane Strut Showing Wing Fittings, and Turnbuckles and Clevises at Fitting End of Flying and Landing Wires.

This system of marking also insures that the struts are not inverted. To accomplish this, all numbers on the struts have been painted so that they may be read from the pilot's seat. By this method an inverted strut can quickly be detected.

The upper left wing panel is first equipped with the front and rear masts by inserting the masts into their sockets on the upper surface of the panel. Then connect up the mast wires to the anchor plates, which will be found on the upper surface of the right and left mast-socket. Use the turnbuckles to adjust the tension of these wires, until the front and rear wing beams become straight in a vertical plane.

Stand the upper left wing panel and the lower left wing panel on their leading edges, properly supporting the panels in cushioned blocks to pre-

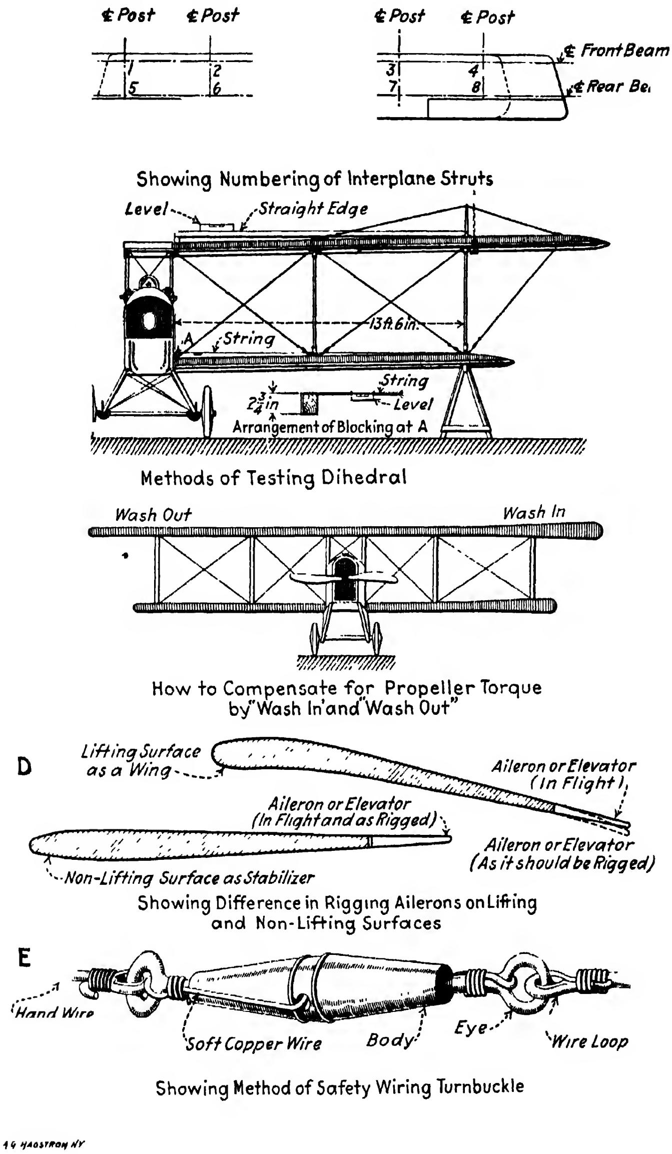


Fig. 267.—Diagrams Illustrating Rigging Instructions.

vent damage to the nose. Space the panels apart, approximately equal to the length of the struts.

Next the diagonal cross wires must be connected up. Connect these loosely to permit the easy entering of the posts into the sockets. The wires

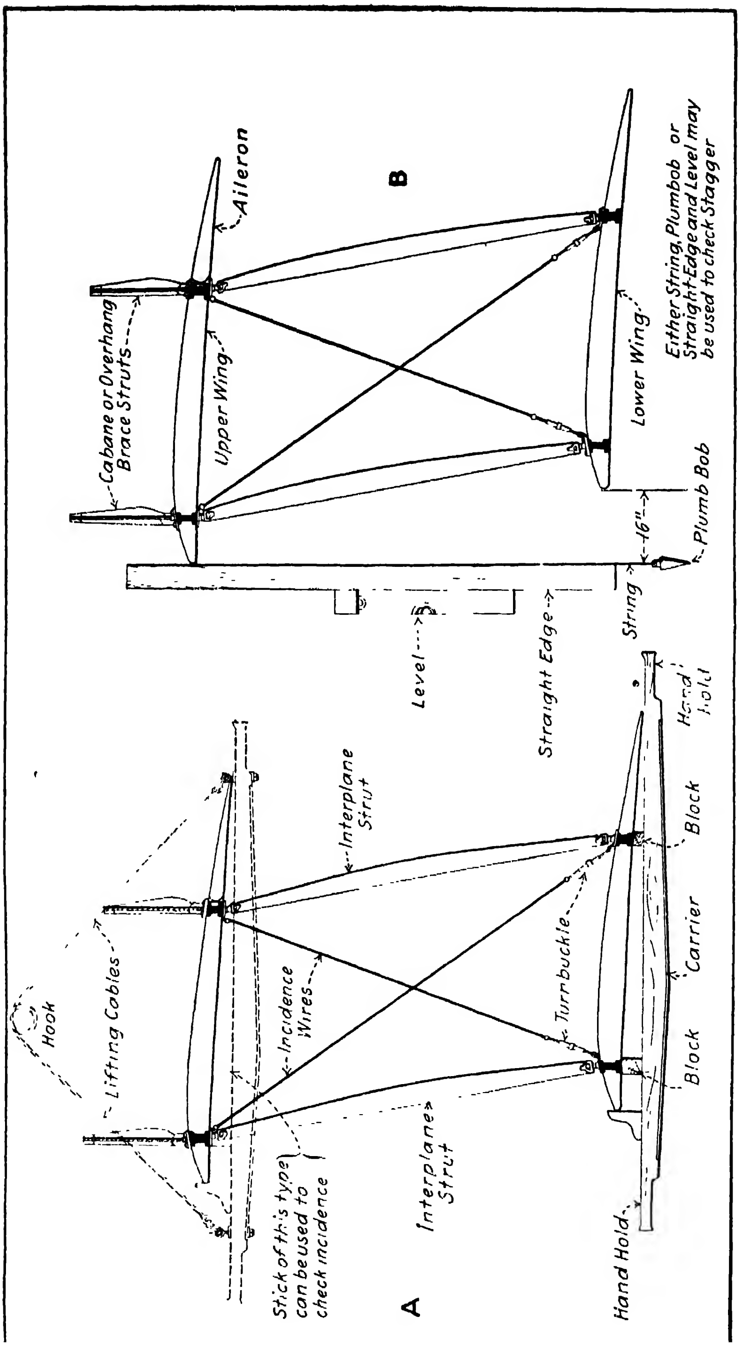


Fig. 268.—Carrier for Panel Assembly at A and B. How to Test for Stagger.

must be connected before the posts or struts are set in place, because if the latter are in place the connecting of the wires to the lugs of the sockets is quite difficult. After these wires are thus inserted, insert the posts and bolts into place.

Connect up loosely the landing (single) wires and flying (double) wires

of the outer bay to hold the wings together as a unit. The outer bay is thus completely wired, though but loosely.

The posts that are used for this left side are Nos. 1, 2, 5 and 6, according to the diagram. No. 1 is the outer front, No. 2 the inner front, No. 5 is the outer rear, and No. 6 the inner rear.

The wings may now be erected to the fuselage. Extreme care must be used to prevent straining or breaking them. In carrying, use boards under the wing beams so that these take the strain off the load. Handling the wings by using the posts as carriers or by attachments to the leading or trailing edges should not be attempted.

The wings must be firmly supported by slings or wooden horses. The wings will have the approximate stagger if assembled as above, as the posts are in place and the tension wires are adjusted to almost correct length when shipped. Insert the hinge pins through the hinges as now coupled up.

If an overhead crane or telpherage system is at hand, the carrier shown at Fig. 268 can be used as shown by the dotted installation. The lower (illustrated) condition is convenient for hand transportation. One carrier should be inserted under each panel point of the wings (next to the interplane posts), care being taken to use filler or spacer blocks under the main wing spars to carry the load and not take the weight on either wings or fabric as this will surely injure these parts.

Adjustment for Dihedral.—The fuselage must now be leveled up transversely and longitudinally. A spirit level placed across the top longerons will determine the transverse condition. With the level placed fore-and-aft on the longerons aft of station 5, the longitudinal level is established.

Adjust the tension on the flying and landing wires until the dihedral of one (1) degree is established, also to make the leading and trailing edges parallel and straight. The amount of lift for the one (1) degree dihedral is 2¾ inches in 13 feet 6 inches (distance from the inner edge of the panel to the center line outer post). An easy method for checking the correct adjustment of the dihedral is to place a block 2¾ inches high on the upper surface of the lower wing, at the extreme inner edge. A straight edge resting on this block and on the upper surface of the wing (straight edge kept parallel to front or rear beam) should be level, Fig. 267 B.

This may also be checked by using a light spirit level suspended from a string or copper wire stretched over the given range. If a block 2¾ inches high be clamped to the inner edge of the panel, and a line pulled taut from this block to the center line of the outer beam, the level suspended next to the block will be sufficiently sensitive to determine the required degree of dihedral. Fig. 267 B shows the arrangement diagrammatically.

If the outer end of the wings is too high, the landing (single) wires are too short and the flying (double) wires are too long. Hence, tightening up equally on the inner and outer front and rear flying (double) wires will correct this condition. If the panels are too low (dihedral not up to one degree), reversing the above method corrects the condition. The opposing wires must also be properly readjusted.

Three Methods of Checking Dihedral.—During the adjustment for stagger and dihedral the rigging for supporting the panels must be maintained in place. Do not safety wire one side until the opposite side has been

erected. The machine will then be equally loaded on both sides. Go over the dihedral and stagger dimension to check up any possible change. When both sides agree with the specified values, safety wire all turnbuckles as shown at Fig. 267 E.

First Method. 1 inch vertically in every 57 inches horizontally equals one degree dihedral.

Second Method. Multiply the sine .0175 for every inch laterally equals one degree dihedral.

Third Method. Use straightedge and Starrett protractor as a dihedral board.

Checking Stagger.—First Method. The plumb line can be conveniently tied to the base of the wing mast on the upper panel. When checking the stagger at the inner end, the string may be attached to any of the upper panel upper surface fittings.

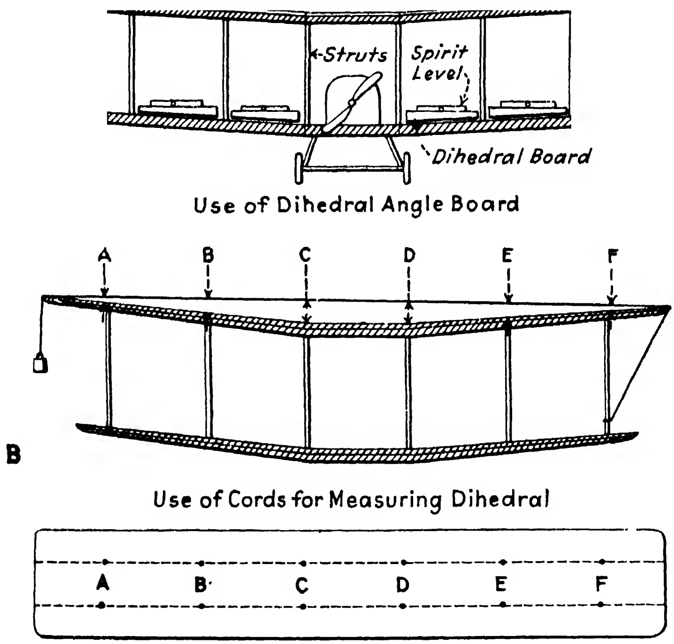


Fig. 269.—Use of Dihedral Board Shown at A. Checking Dihedral by Measurements Shown at B.

Second Method. A straightedge set vertically by plumb (level) is practical field method for checking up. Both of these methods are shown at Fig. 268 B.

Wash-in and Wash-out.—The turning of the propeller produces a tendency to turn the whole airplane around in the opposite direction to that in which the propeller is running. This tendency was very marked in some

of the earlier machines, especially the small monoplanes. This is overcome in some machines by increasing the angle of incidence of the plane on the side which would tend to tip down and in some cases to decrease the angle of incidence on the other side. By so doing there is slightly more lift on one side of the machine than on the other, which corrects the tendency to turn around the center line of thrust. Two terms which are used in this connection are "wash-in" and "wash-out." When the angle of incidence increases from the center to the end of the plane it is called "wash-in," and when it decreases from the center to the ends it is called "wash-out." This is clearly shown at Fig. 267 C.

Empennage or Tail Assembly.—The horizontal stabilizer, vertical stabilizer, rudder, and elevators are assembled to form the empennage. As shown at Fig. 271, the horizontal stabilizer is mounted at the rear end of

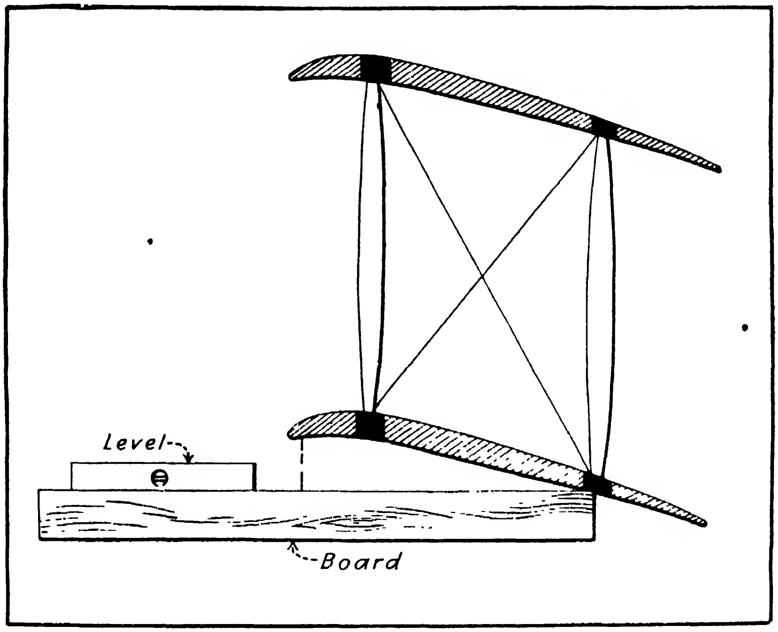


Fig. 270.—How to Check Angle of Incidence of Wings. This is Determined on Most Planes by Location of Wing-Panel Support Fittings on Fuselage.

the fuselage with its lower surface resting on the top edge of the upper longerons. A system of struts arranged from the under side of the stabilizer to the lower longerons and tail post anchors the stabilizer to the fuselage in a fore-and-aft direction. The vertical stabilizer is anchored on the upper center line of the horizontal stabilizer by suitable clips and tie-down cables.

The rudder is hung from the end edge of the vertical stabilizer and tail post of the fuselage. The guy lines from the control braces to the trailing edge are so fixed as not to interfere with the elevators during any position of operation. The upper edge of the rudder is in a continuous line with the leading edge of the vertical stabilizer. The elevators are arranged on the trailing edge of the horizontal stabilizer. The inner edges of the elevators

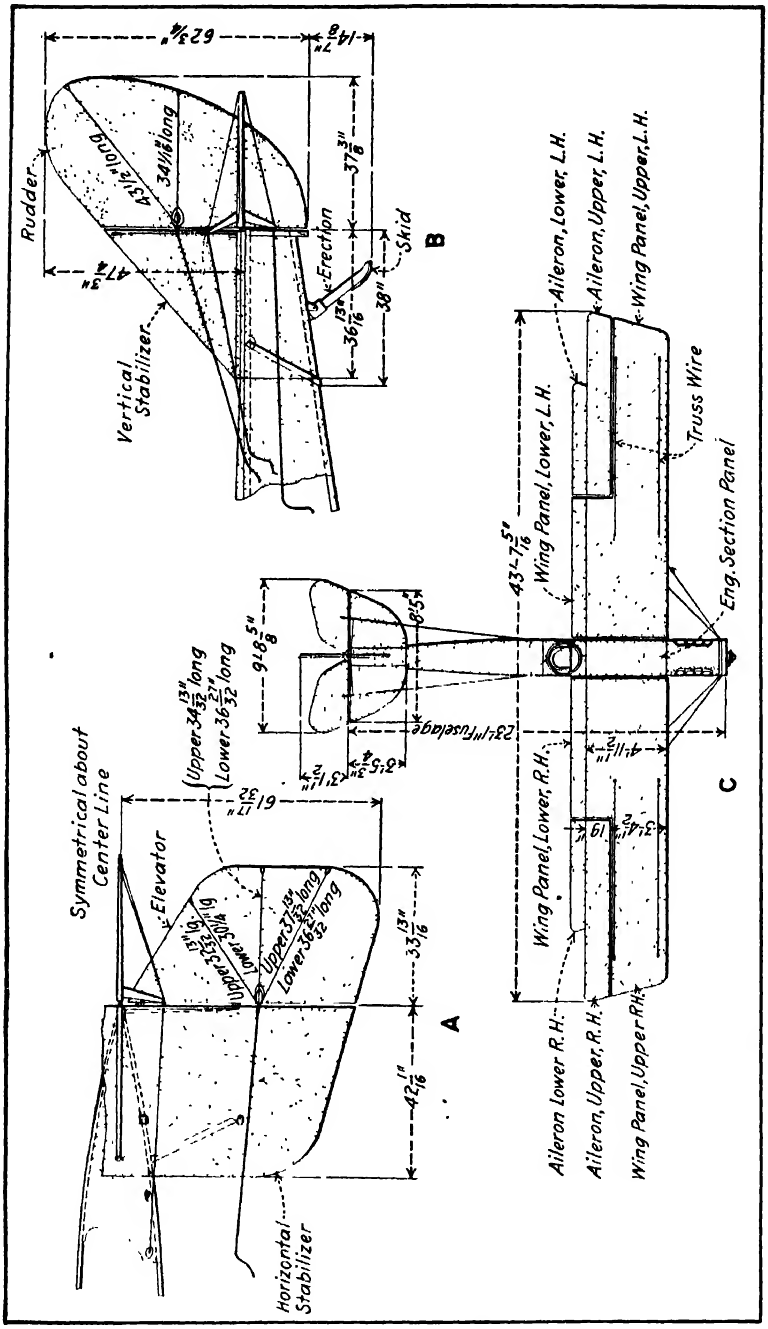


Fig. 271.—Diagrams Showing Main Dimensions of Curtiss JN4 Training Biplane. A—Plan of Assembly of Horizontal Stabilizer and Elevator. B—Assembly of Vertical Fin and Rudder. C—Plan View of Airplane with Wings and Empennage in Place on Fuselage.

are fixed so as to permit of operation of the rudder through an arc of at least 30 degrees each side of the fore-and-aft center line.

Landing Gear.—The landing gear is of the "V" type cross-braced construction. It is composed of two trusses, properly separated and cross-braced. The lower ends of the members of each side truss end in the fittings of the continuous cord shock absorber bridge. The landing gear is connected to the lower longerons with proper fittings. The axle is properly streamlined. The bridge is so aligned vertically as to permit an upward and downward movement of the landing gear axle. The shock absorbing bridge is of the style known as the continuous rubber cord shock absorber.

The shock absorbing unit of the bridge is a continuous built up rubber cord covered with fabric. This cord is firmly wound around the axle saddle, which passes through the steel bridge and rests over the axle on both sides of the struts. The bridge itself is a lightened steel member with a slotted arrangement allowing the vertical movement of the axle. This guide for controlling the vertical movement is curved in a transverse direction to accommodate the vertical rotation of the axle about one wheel in case of a side landing.

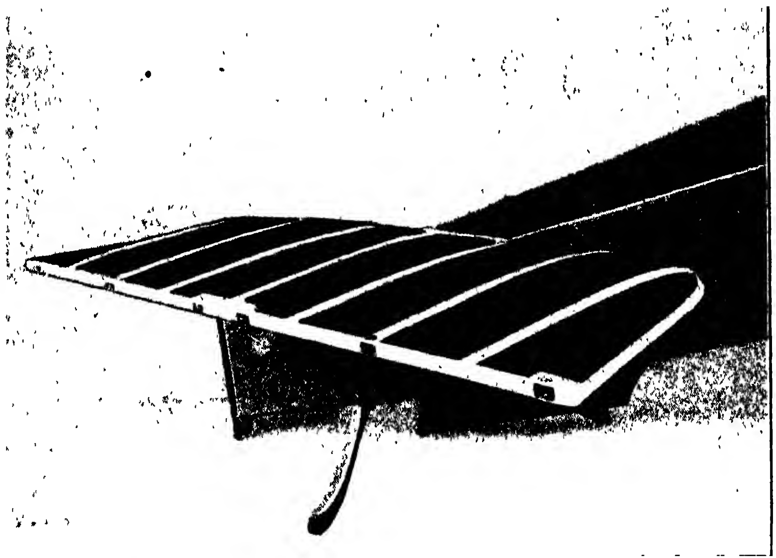


Fig. 272.—Rear View of Fuselage with Horizontal Stabilizer Attached.

Horizontal Stabilizer.—This member is assembled to the fuselage after the upper longeron is levelled up. Each upper longeron has one U bolt and one special bolt to fasten down the horizontal stabilizer. This U bolt is just ahead of the tail and passes under the longeron with the legs pointing upward. These bolts extend through the stabilizer and are fastened with nuts. They serve to hold the leading edge of the stabilizer. Two special bolts are arranged at the tail of the machine so that they extend through the horizontal stabilizer, one on each side of the vertical stabilizer. These bolts also extend through a small L-shaped piece on each side, which is fastened to the vertical stabilizer. This fastens both stabilizers to the tail

of the fuselage. These two bolts are flattened on their lower ends so that they rest against the tail post and are held to it by one bolt running through and by two screws, one on each side. All nuts are castellated and fastened with cotter pins. (See Fig. 272.)

Vertical Stabilizer.—Next, the vertical stabilizer is fastened to the horizontal stabilizer with the bolts which pass through the fore-and-aft parts of the horizontal stabilizer and with the hard wire stay lines running to the upper surface of the horizontal stabilizer from the top of the vertical stabilizer. The forward bolts pass through the clip at the lower front point of the vertical stabilizer. The bolts which are fastened to the tail post of the fuselage, and engage the after end of the horizontal stabilizer, also engage the lugs fastened to the bottom edge of the vertical stabilizer at the rear. The nuts should be drawn up tight and locked with cotter pins. To align the vertical stabilizer hard wire lines and turnbuckles are used. (See Fig. 273.)

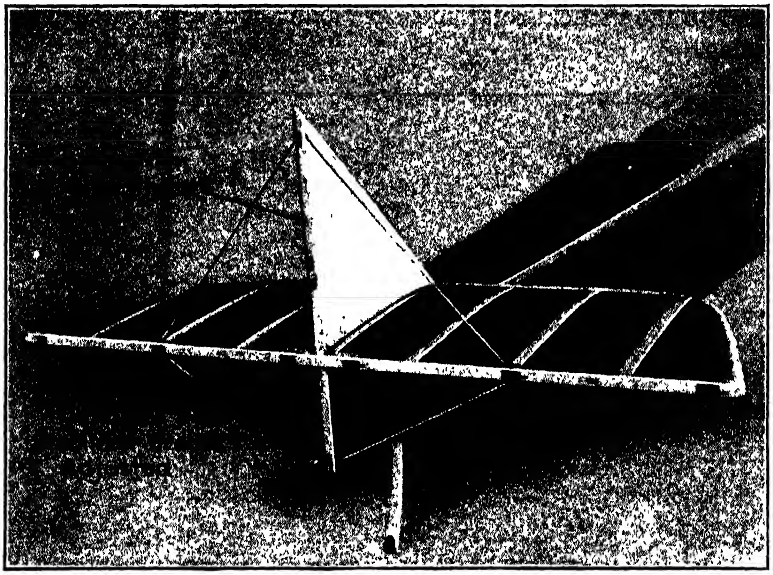


Fig. 273.—Rear View of Fuselage Showing Vertical Fin Assembled and Stabilizer Braces in Place.

Elevators.—In assembling the elevators, first put on the control braces which will be found with all necessary bolts, nuts, and cotters in the case with the wing panels. The position of the base of the control brace is indicated on Fig. 275. The upper tips of these braces point to the hinge line. Hinges and hinge pins are used to mount the elevators to the horizontal stabilizer. Cotter pins are used to keep the hinges in place, and are inserted through the holes drilled in the bottom of the hinge pins. (See Fig. 275.)

Rudder.—The control pylons or braces are first attached to the rudder. They are so placed that the upper tips point to the hinge line, thus matching up the holes. The bolts and nuts for fastening braces to the rudder are

shipped and fastened to the braces. Before mounting the rudder, see that the vertical stabilizer is in plumb alignment with the tail post. This alignment is absolutely necessary. The rudder may now be mounted onto the tail post and vertical stabilizer by means of hinges. The hinge pins are now inserted in the hinges and cotter pins put in the holes at the bottom of the pins and spread backward. (See Fig. 274.)

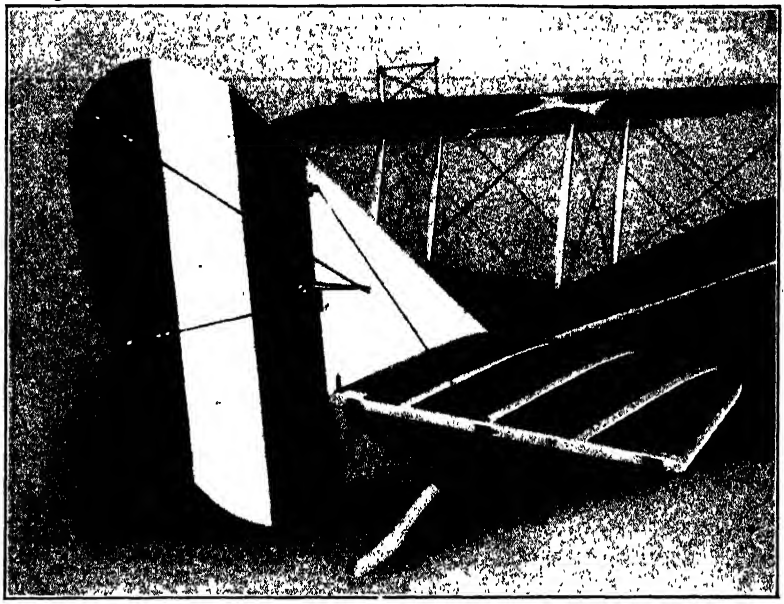


Fig. 274.—Rear View of Fuselage with Vertical Rudder in Place.

Aileron Adjustment.—Attach both ailerons (one on each side of machine, after having mounted control braces to ailerons) and fasten pins of hinges with the necessary cotter pins. Temporarily support ailerons so that their trailing edges are one inch below the trailing edges of the upper panels. Then connect up the flexible tie-line that, passing over the top of the upper wings through fairleads, is connected at the center by a turnbuckle and, passing through pulleys attached to the upper surface front beam, is attached (by shackle and pin) to the upper control brace of the aileron. This "lead" is allowed so that, when in flight, the force of the lift will somewhat raise *both* ailerons and bring their trailing edges on a line with the trailing edges of the panels. Now lead the end of the aileron control line attached to sector through the hole in each side of the fuselage (between front and rear seats). Uncoil the connecting line which passes over the pulley attached to the lower surface of the upper wing near the front outer post. Attach shackle and pin end to lower control brace of aileron, and attach turnbuckle end to loop of aileron control lead attached to control sector in fuselage (and which passes through side of fuselage). In making this last attachment, the leads should be so arranged (by moving the stick of the controls) that the lengths projecting through the fuselage are equal.

Rudder Control Adjustment.—Uncoil the lines attached to the rudder bar, to lead out through the upper surface of the rear end of the fuselage cover, and, keeping the rudder control bar at right angles to the longitudinal axis of the machine, fasten the ends to the control braces. Next take up the slack of the lines by means of the turnbuckles, adjusting the tension equally in each set; the rudder control bar (foot control bar) should remain at right angles to the longitudinal axis when the rudder is neutral (or in a vertical plane through this fore-and-aft axis).

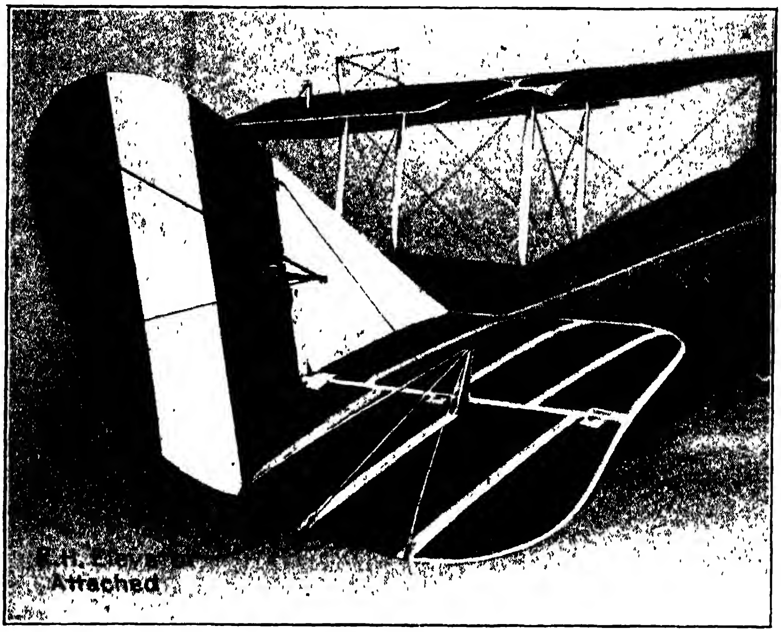


Fig. 275.—Rear View of Fuselage with Right-Hand Elevator Flap Installed.

Elevator Control Adjustment.—Temporarily maintain the elevators in the plane of the horizontal stabilizer (neutral position). Move the stick forward until the distance between the instrument board and the nearer surface of the tube of the stick is nine and one-half (9½) inches. By fixing this distance from the instrument board or dash to the tube of the stick, a slight lead is given to the control for the greater range for raising the elevators. Now uncoil the wires leading from the clips attached to the walking beams of the stick control, and coiled up aft of the pilot's seat. Pass the wire attached to the lower end of the beam out through the side of the fuselage, through the lower of the two vertical holes, aft of the pilot's seat. With the control stick lashed, or fastened, to the nine and one-half (9½) inch position, connect this wire to the lower control brace of the elevator. Repeat operation for other side of machine.

Similarly the wire attached to upper end of the walking beam is passed through the upper hold in fuselage side, and attached to the upper control brace of the elevator. Photograph at Fig. 276 shows the general arrangement of the control wires at the rear of the fuselage. Adjust tension in

these wires by means of turnbuckles, so that all lines have the same degree of tautness. The elevators will then be neutral for this position of the bridge.

General Instructions.—All connections having now been made, carefully go over each shackle, pin and turnbuckle, and see that all pins are properly in place, all nuts on bolts tight, and all cotter-pinned. Try out all controls for action and freedom of movement. See that no brace wires are slack, yet not so taut that, when plucked, they "sing." Attach nose or drift wires leading from nose of machine to intermediate posts, front and rear. The lower wire connects up with the lower front socket on the upper surface of the lower panel; the upper wire connects up with the upper rear socket plate on the under side of the upper panel, after the panels are attached to fuselage, with stagger and dihedral properly corrected.

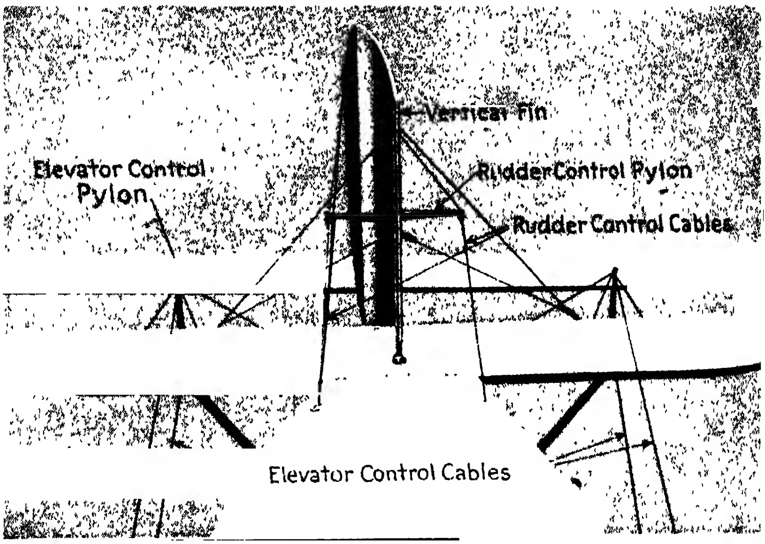


Fig. 276.—View of Airplane Fuselage Rear with Elevator and Vertical Rudder Control Cables in Place.

Checking Alignment of Wings and Fuselage.—To align the cellule accurately with the fuselage, measure carefully from rudder post A to the rear outside bolts B of outside strut fittings; from front bolts C of outside strut fittings to the propeller shaft D. If the parts are in correct alignment, distances C-D will be equal to each other and distances A-B will also be the same on both sides of the machine. This method is clearly outlined at Fig. 277.

String and Straightedge Method of Aligning a Fuselage.—1. True up the two front struts of the landing gear by diagonal measurement from corresponding points on the axle.

2. Square up the master struts with the top and bottom longerons by adjusting the interior cross wires. If there is any difference in the width of the top and bottom longerons, make it equal on each side. Also note that the engine beds are parallel by proper adjustment. When adjusting

one set of side wires, always loosen the cross wires in section to be next adjusted.

3. Square the top longeron of No. 1 section on one side of fuselage with the center line of the master strut lengthwise. Raise or lower opposite front flying strut until longeron of same section is parallel with tops of master struts using the cross wires in the No. 1 section for this adjustment.

3a. To sight top longeron on one side parallel with the longeron on other side, place a white board about three feet long by 12 inches wide across top longeron, just forward of master strut fittings; place a black straightedge across longerons just back of master strut fittings with the white board for a background; place a white straightedge across top longerons just back of front flying strut fittings. Now sight from the rear of the tail post, raise or lower side to be adjusted until the top of the white straightedge coincides over its entire length with the top of the black straightedge.

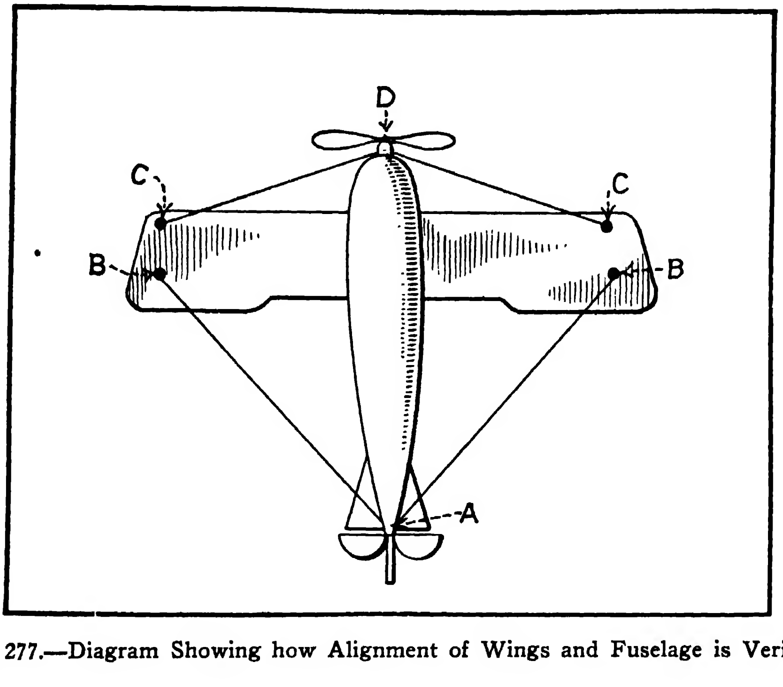


Fig. 277.—Diagram Showing how Alignment of Wings and Fuselage is Verified.

4. Square up the side of the top longeron in No. 1 section lengthwise with the tops of the master strut fittings by adjusting the bottom cross wires in the No. 1 section. Then square up the sides of the front flying struts with the top longerons. This completes the No. 1 section.

5a. Now stretch a string from each side of the top longeron at the master strut fittings (held 1 inch from the side of the longeron by a stick 28½ inches long laid across fuselage) to the tail post (held same distance apart by a straightedge laid across center of last section).

5b. Place white straightedge in front of the rear flying strut fittings. Hold the string against the bottom of this white edge and raise or lower the

rear flying strut until the string is flush with the top of longeron, at the front of flying strut, then sight straightedges until tops coincide. (If, when the straightedges sight parallel, the string does not check flush with the longerons at the last adjusted strut, then the strut should be readjusted before proceeding further.) This makes the top longerons parallel in No. 2 section.

5c. Square the sides of the rear flying struts with the top longerons, equalizing the difference, if any, using the interior cross wires for this adjustment.

5d. Make the sides of the top longerons straight lengthwise by adjusting the bottom cross wires of No. 2 section until the string is the same distance from the longeron at the rear flying strut as at both the master strut and the front flying strut, and the No. 2 section is completed.

6. Now tighten carefully the rear cross wires of the landing gear until they are sufficiently taut and the same tension.

7. Repeat 5a, b, c, d, in No. 3 section, but check string flush with tops of longerons at rear flying struts instead of front flying struts.

8a. In section No. 4 make longerons parallel and straight as before and then square up the sides.

8b. With side strings equal distance from each master strut and No. 1 strut, tie another string on the center of the No. 1 top cross strut and the center of the string spreader (straight edge) at tail. As the longerons taper inward from the No. 1 strut to the tail post the above string is used to get the fuselage straight by checking with the center lines on top cross struts.

9. After getting No. 2 top cross strut central, center string may be loosened from the tail fastening and the remaining cross struts may be made central by holding the string on the center mark of each strut and adjusting to the right or left until string coincides with center mark on No. 2 top cross strut.

10. To get the longeron straight at the tail post, place three cubes (each 1½ inches square) on top longeron at last three sections, and adjust tail post until tops of all three cubes are flush with the straightedge placed on them.

11. The tail post should be square with the sides of the fuselage and to make it so, place a large square across the tops of the top longerons at the stabilizer section, letting one side of it hang parallel with the fuselage; and with a straightedge against the upper and lower rudder hinge fittings sight across or along the edge of the straightedge and the hanging side of the square, adjusting wires in the last section until the tail post comes square.

12a. Engine bed and engine section. The rear ends of the engine bed pieces are parallel with the top longerons by their construction and the entire length of the engine bed pieces is made to coincide with the rear ends by adjusting the side cross wires of the engine section. First ascertain which side of the engine bed is high, then place a straightedge on top of the top longerons over strut forward of the master strut. If the same side shows high, then adjust by the cross wires in the section next to the master strut. But if the longerons are parallel, crosswise at this point, then raise

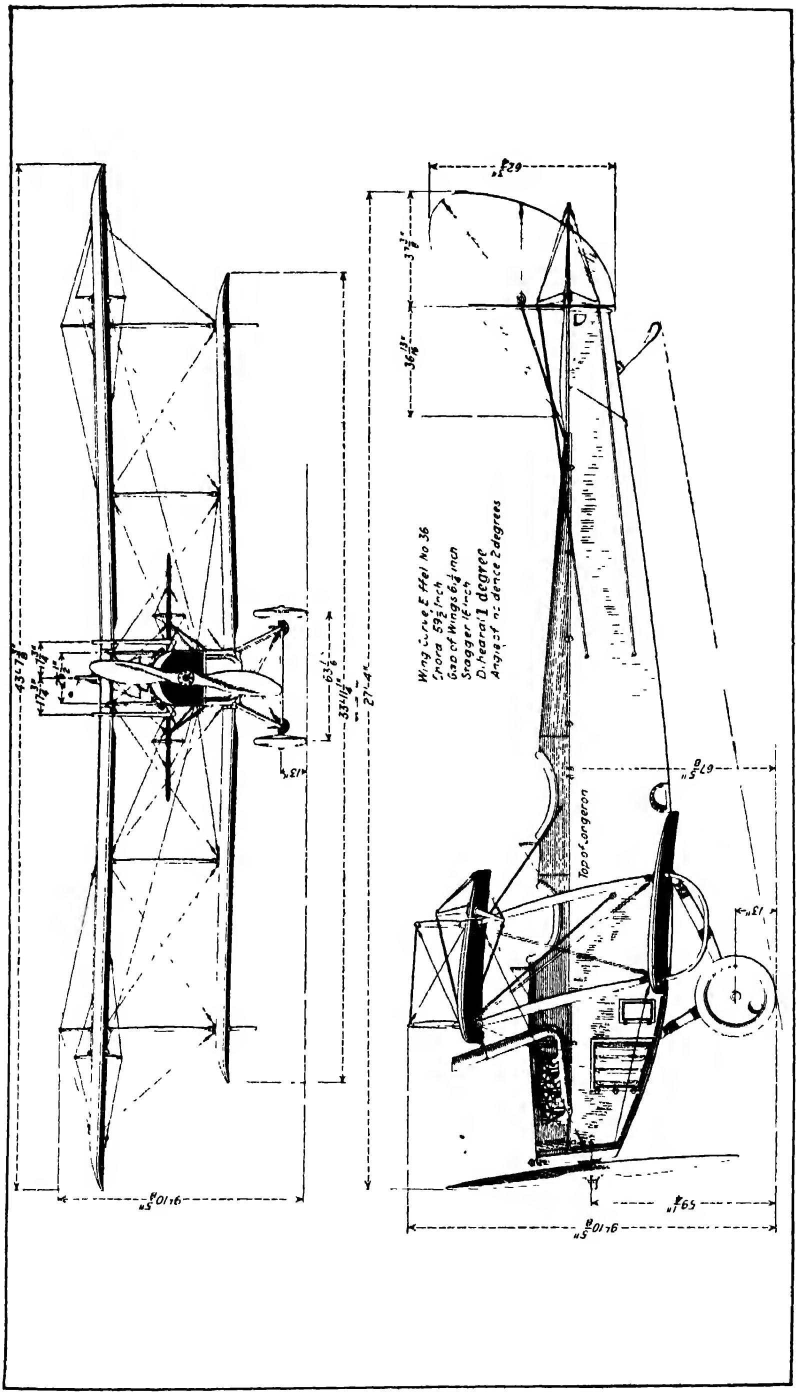


Fig. 278.—Diagrams Showing Dimensions of Widely Used Curtiss JN4 Training Biplane, a Popular and Widely Used Wartime Design of Great Reliability and Easy Control. Thousands of These Machines have been Used in Civilian Flying.

the nose by adjusting the cross wires in the nose section until the front end of the engine bed pieces are parallel crosswise with the rear end.

12b. Raise or lower both sides of the entire engine section until engine bed pieces are parallel lengthwise with the tops of the longerons.

12c. Fasten strings at a set distance from the side of lower longerons at the rear flying struts to the side of the lower longerons at the nose of the fuselage. Now adjust the nose of the fuselage to the right or left until the string is the same set distance from the side of the master struts. This should align the fuselage practically accurate.

Fuselage alignment is very important as much depends upon its accuracy. If the rear end is not true and level, the flying qualities will be impaired because the empennage will be twisted instead of in its correct plane. Any lack of alignment will be indicated by erratic flight. Just as it takes a straight, true arrow to hit its mark, so it takes a well aligned fuselage to insure true flight and ready control.

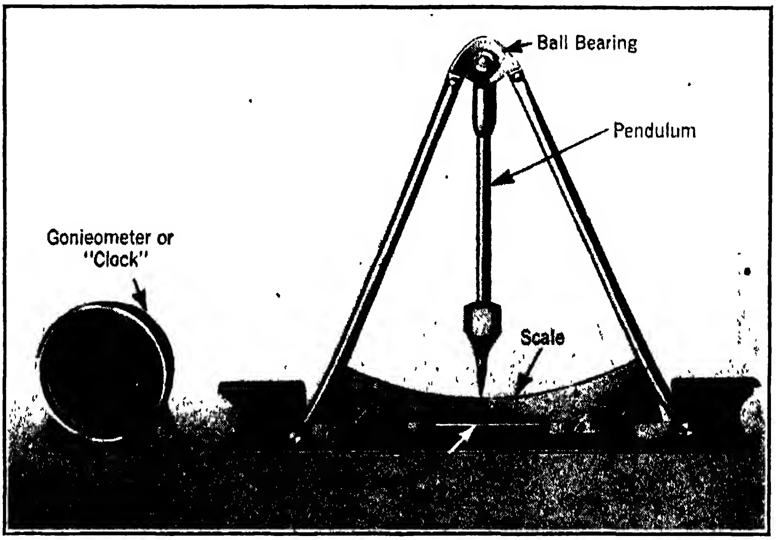


Fig. 279.—Instruments Used in Checking Airplane Alignment. A—Clock or Goneometer. B—Extemporized Level and Pendulum Arrangement to Check Incidence Dihedral and Other Angles.

The Curtiss JN4 Airplane was a pre-war development and has been generally described in the aviation prints, so its construction and detail features are so well known and so many of these airplanes have been used in civilian flying since the close of the war that a review of the main dimensions and features of this thoroughly tried, safe and practical airplane, which is reproduced from the instruction book of the makers will be of value to the student. This airplane is clearly shown at Fig. 278 and is an excellent example of conservative yet reasonably modern airplane design. The writer had considerable experience with the Curtiss JN series while Chief Engineering Officer at Hazlehurst Field, Mineola, L. I., early in the war where several hundred such planes were under his direct supervision. They were so reliable that a record was established during an entire flying

season of having more miles flown per unit equipment than any other field in the United States and this was done despite the rush and stress incidental to wartime training of pilots, *without a fatality*. Flying fields using some other makes were not so fortunate. For this reason, the writer, will always have a soft spot in his heart for the old "Jenny," as this model is known wherever airplanes are spoken of.

General Dimensions:

Wing span—upper plane	43 ft., 7⅜ in.
Wing span—lower plane	33 ft., 11¼ in.
Depth of chord	59½ in.
Gap between planes	60 in.
Stagger	16 in.
Length of machine, over all	27 ft., 4 in.
Height of machine, over all	9 ft., 10⅝ in.
Normal angle of incidence of panels	2 degrees
Dihedral angle	1 degree
Sweep back	0 degree
Angle of incidence of horizontal stabilizer	0 degree

Areas:

Upper planes*	167.94 sq. ft.
Lower planes*	149.42 sq. ft.
Ailerons (each 17.6 sq. ft.)*	35.20 sq. ft.
Horizontal stabilizer	28.70 sq. ft.
Vertical stabilizer	3.80 sq. ft.
Elevators (each 11.00 sq. ft.)	22.00 sq. ft.
Rudder	12.00 sq. ft.

Weight:

Net weight, machine empty		1430 lbs.
Gross weight, machine loaded		1920 lbs.
Useful load		490 lbs.
Fuel (21 U. S. Gals.)	130.0 lbs.	
Oil	30.0 lbs.	
Pilot	165.0 lbs.	
Passenger	165.0 lbs.	
Total	490.0 lbs.	
Loading per sq. ft. supporting surface		5.45 lbs.
Loading per R. H. P.		21.35 lbs.

Performance:

Speed, maximum, horizontal flight	75 miles per hr.
Speed, minimum, horizontal flight	45 miles per hr.
Climb in 10 minutes	2000 ft.

Motor:

Model OX-5, "V," four-stroke cycle, 8-cylinder, water-cooled.

Horsepower (rated at 1400 R.P.M.)	90
Weight per R. H. P.	4.33 lbs.
Bore and stroke	4 in. x 5 in.

*Total supporting surface, 352.56 sq. ft.

General Rules For Assembly and Alignment.—During the late war, the writer for a time immediately preceding the armistice was Chief Aeronautical Engineer at the 3rd Aviation Instruction Center of the A. E. F.

which was located in the country surrounding and adjacent to the towns of Issoudoun and Vatan, Indre, France. This flying center consisted of fifteen flying fields and each field made use of a different type of airplane, ranging from clipped wing Penguins or "Roulers" on the field where the first training was given to Spads and DH planes for most advanced training. In all, there was seventeen different types of airplanes in daily use and the total number of planes available at all fields was over 1,000, ranging from slow training planes of even then obsolescent design to fast scout planes of the latest types. One of the makes of planes used in the greatest number was the Nieuport in its various types.

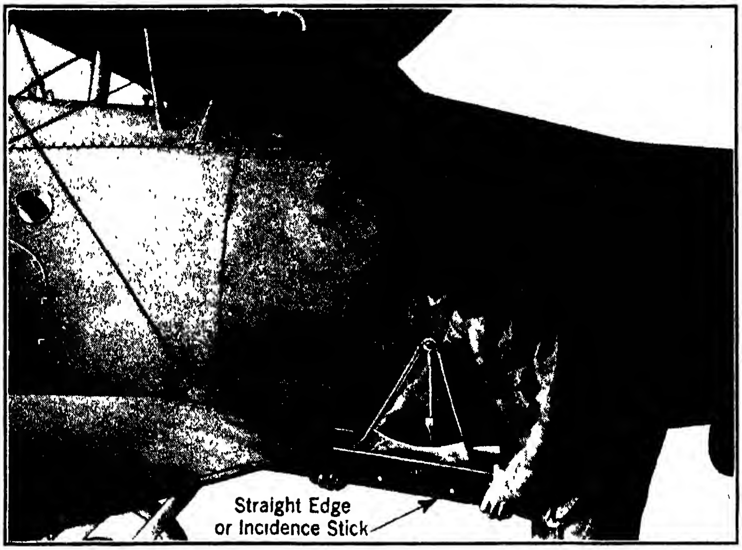


Fig. 280.—How Level and Pendulum Arrangement is Used to Check Incidence of Lower Biplane Wing.

In getting out orders for assembling and alignment, the authorities were somewhat handicapped because specific instructions given for one type did not always apply to the other makes so some general rules were promulgated by the Technical Department that were of value in that they formulated basic principles of procedure to be followed in the case of all airplanes. As these may be of interest, they are reprinted. Two instruments that were found of great value in connection with the assembling and maintenance of airplanes at this flying center are shown at Fig. 279. That at left was known as the "clock" by the men but was called a goneometer by the makers. It gave a range of angle readings from 0 to 45 degrees in either direction, the reading being obtained direct by an indicating needle pointing to the divisions on the face.

An extemporized instrument, not so fancy in appearance but just as effective in service was built at the field instrument shops to give direct readings of angles. A steel level formed the base of the device, from which

a tubular V framework extended upward. At the apex of the V a ball bearing carried a pendulum member, well weighted at its lower end. The pendulum bob carried a pointer which registered with graduations on a protractor like scale, this giving readings up to 20 degrees in either direction. This is shown at the right of the photograph Fig. 279. The method of using it in connection with an incidence stick is shown at Fig. 280 while one of the uses of the goneometer is shown at Fig. 281, an application obviously impossible with the level and pendulum contrivance.

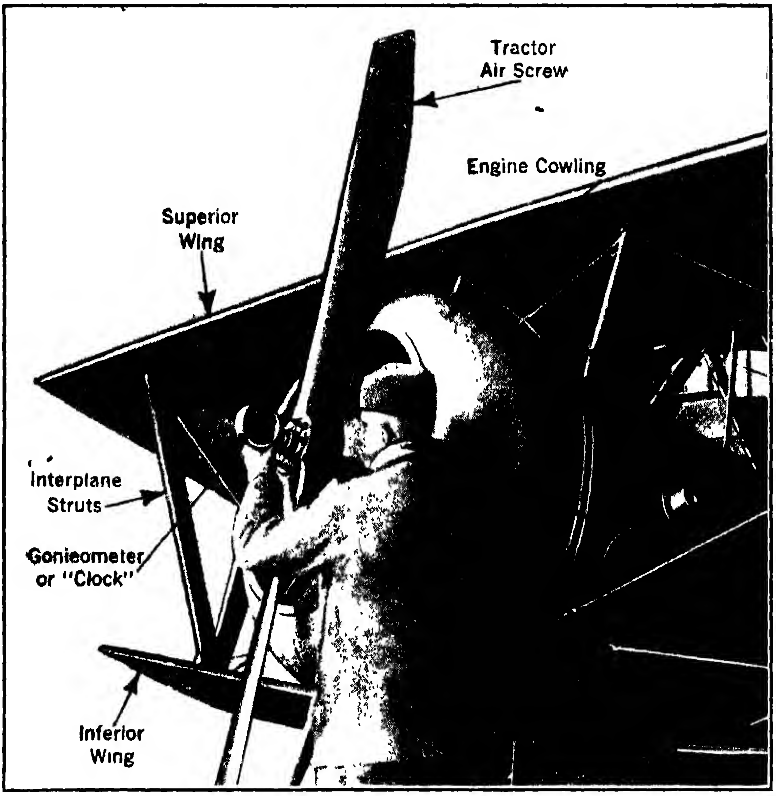


Fig. 281.—Goneometer Shows Angles in Any Position. May be Used for Vertical or Horizontal Surfaces.

First Step in Assembling a Plane.—Place the fuselage in a flying position. This is done by blocking up the tail and undercarriage until the longerons at the cockpit are level transversally and longitudinally. A reading is taken by placing a straightedge across the top longerons and using a goneometer; pendulum or level. If the plane is correctly blocked up, the reading will be zero. The string and plumb bob system shown at Fig. 282 may be used if the fuselage has been repaired. The method of support with wheeled landing gear in place is shown at Fig. 283.

Assembling Empennage.—Attach elevator to stabilizer, making sure that in case of a cambered elevator or stabilizer, the camber on each is equal; and that the necessary lock washers and split pins are correctly in-

stalled. Fasten stabilizer on fuselage, and adjust bracing tubes and wires until stabilizer is level transversally. This is done by placing a straight-edge transversally and longitudinally across the stabilizer. A reading taken at this point will be zero; as at the cockpit.

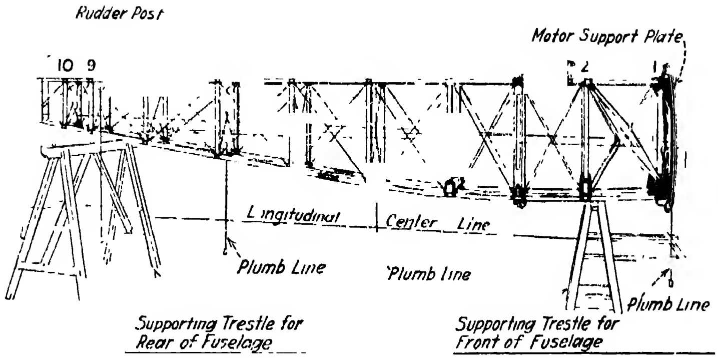


Fig. 282.—Method of Fuselage Alignment by Plumb Bobs and Lines, Checked by Level Center Line.

If the plane has a fin; this should be attached next, care being taken to place the fin perpendicularly in line with the longitudinal axis of the fuselage. Then attach rudder, making sure that hinges work freely and fittings are securely locked. If stabilizer is set at either positive or negative incidence, it is checked with an incidence stick and goneometer as shown at Fig. 285.

Assembling Main Planes.—On some types of planes the wings are assembled before being fitted to the fuselage. When this is the case, care should be taken that struts are exactly the same length and that they are properly fitted in their bearings. A slight tension should be placed on wires

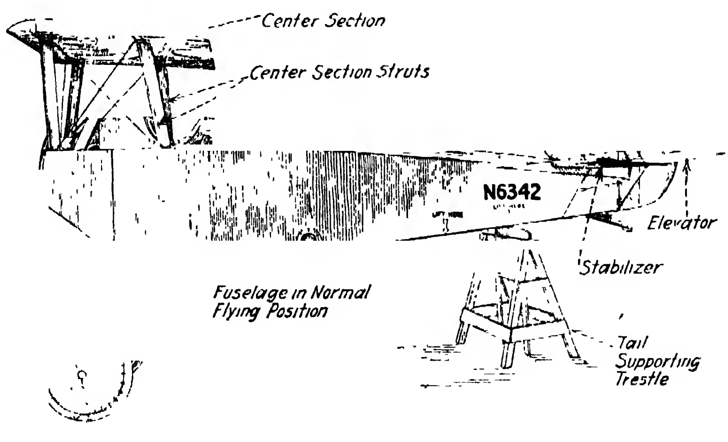


Fig. 283.—Fuselage Shown at Fig. 282 with Center Section and Landing Gear Installed. Note Use of Trestle to Support Tail in Flying Position.

to hold the wings in position while attaching them to fuselage. On other types where the wings are attached separately, the lower or inferior wings are attached first and held in position by supports placed under the outer struts bearings. The struts are then attached to the upper or superior wings. Attach the wings to the center section struts, and bolt the interplane struts to the inferior wings. Flying and landing wires are then connected loosely, making sure that all turnbuckles fit properly and have the required number of threads.

Center Section.—In case of a plane having a fixed center section as in the type shown at Fig. 283, this should be trued up before wings are attached. The center section should be symmetrical about the vertical center line of the fuselage, and is adjusted by cross bracing wires which should be equal when checked by a trammel. A reading taken transversally across the top, should be zero.

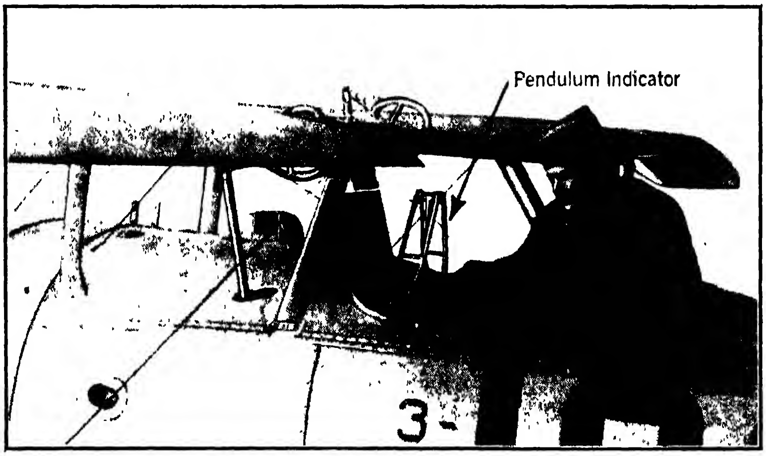


Fig. 284.—Using Pendulum Indicator and Level to Check Fuselage Alignment.

When the stagger is not fixed, it should be checked by plumb lines dropped from the leading edge of the center section on either side, so as to clear the fuselage longerons to a mark determined upon by measurements from the leading edge of the lower wings. Adjustment may be made by drift and anti-drift wires.

Alignment.—Tension all wires and line up plane with the eye. This is done by placing a straightedge along the spar of the superior wing as at Fig. 286, and another transversally across the stabilizer; then adjust cables until both straightedges are parallel to each other. The trailing edges of both superior and inferior wings are also set parallel, which is done by adjusting both rear landing and flying cables. Then check by goneometer.

On planes with no dihedral, a reading taken from a straightedge placed laterally along the spar of the superior wing, should be zero. In case of planes having a dihedral, adjustment may be made by the front flying and landing wires until the desired number of degrees dihedral is obtained. Incidence is then taken by placing a straightedge along the chord of a rib on both superior and inferior wings, nearest the origin of the wing and the

outer strut. This reading will give the number of degrees incidence of the wings as at Fig. 287. The incidence on the superior wings of most planes is set at a fixed angle and can only be changed by lengthening or shortening the front struts. On some types of planes, the inferior wings are adjustable, and different angles of incidence may be obtained by turning the wing, after loosening the collars of the strut bearings and compression tube.

Stagger.—Planes with a stagger are checked by plumb lines dropped over the leading edge of the superior wing corresponding with the center section. The required amount of stagger is obtained by adjusting stagger wires, and rear flying and landing wires. Measurements to determine amount of stagger are taken from leading edge of inferior wing to plumb line.

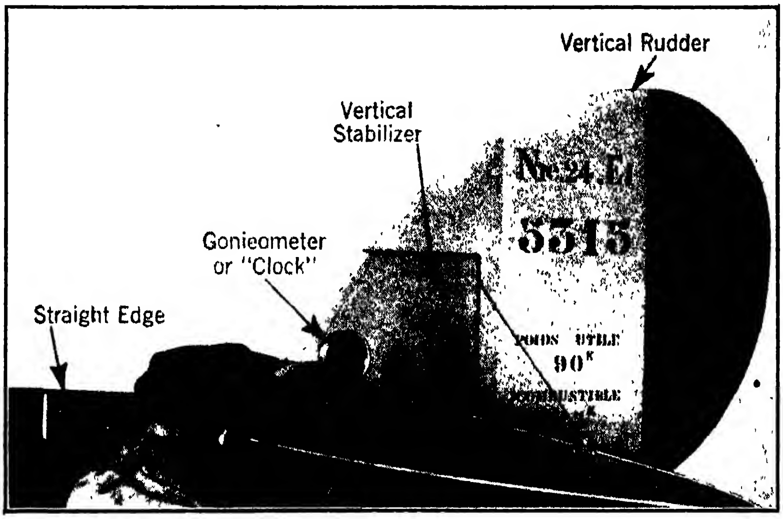


Fig. 285.—Using Goneometer and Incidence Stick to Check Rear Stabilizer.

Outside Measurements.—The plane should be checked up by a series of measurements as follows:

1. A line drawn from the center of the propeller hub to a fixed point on the strut of the inferior wings; the distance on both sides should be equal. Adjustments are made by drift wires.

2. A measurement is taken from a fixed point on the outer edge of the stabilizer to a point on the inferior wing strut; the distance on both sides should be equal.

3. The undercarriage is now trammelled and adjusted by cross bracing wires until diagonals are equal.

Controls.—Elevators, with stick in neutral, should be in line with the stabilizer, which is in line of flight. Control wires should be adjusted until this is the case. Rudder, with rudder bar square with fuselage, should be directly in the center line of the machine. Adjustments are made with control wires. Ailerons, with stick in neutral, should be in line with the wings. Adjustments may be made with control rods or wires. In some cases, a slight droop is given to make the plane more sensitive, and to make up for any lost action in controls.

Inspection.—Great care should be taken in the first inspection of a plane after assembly. Examine all wires for broken strands and poor splices; see that wires have an equal tension; that turnbuckles have required number of threads and are properly locked. Where control wires pass through guides or over pulleys, care should be taken that there is no danger of jamming or undue friction. All wires should be given a light coat of grease after inspection to prevent rust.

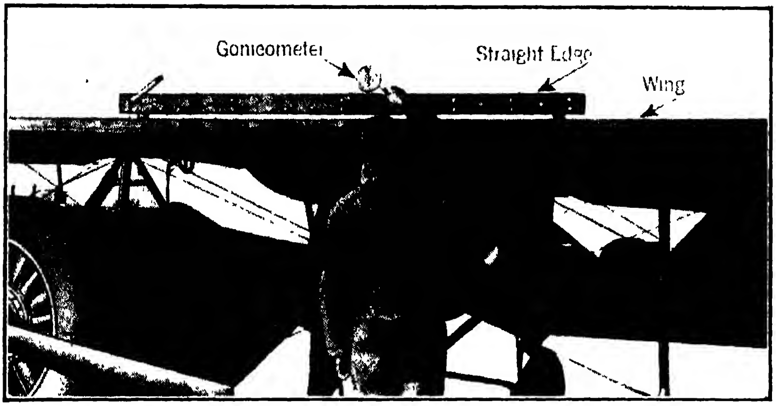


Fig. 286.—Using Goneometer and Straightedge to Check Wing Panel Dihedral.

Fittings, bolts and clevis pins. See that all nuts are properly tightened and locked with lock washers or split pins, care being taken that where possible, nuts should be in uniform position so as to facilitate easy inspection. Clevis pins should be snugly fitted in holes in fittings and should be placed so that split pins will be down. Examine all fittings for cracks and flaws. See that all struts are properly bedded in their fittings, and examine for cracks or flaws and check with straightedge for bowed struts.

Fuselage and Wings. Examine wings for broken ribs, loose lamination and holes in fabric.

Controls. See that controls work freely and that there is no lost motion.

Installation of Motor.—Motor should be given thorough inspection before installing in plane. In case of a stationary motor, the motor bed longerons should give a zero reading when checked longitudinally and transversally. On a rotary motor, a reading taken from the propeller hub should be zero. If motor is in line of flight, 3 degrees negative or positive is allowed, however, care should be taken that the motor is securely fastened to its bed; if not, undue vibration will result. Propeller should be checked for trueness in its track.

Inspection Before Flight.—See that gas and oil tanks are filled, and examine them for leaks, loose connections; et cetera. See that motor turns up the required revolutions, and that all instruments are adjusted and work properly. Give plane a final inspection, checking up all parts previously inspected. See that shock absorbers have the required number of wraps, and are properly tensioned; that tires are properly inflated. The most common faults disclosed by flight testing will be found in the lateral and longitudinal

stability of the plane. In case of lateral instability, the correction is usually made by increasing the incidence on the side that is to be corrected. Longitudinal instability can be corrected by adjustments on the wings or stabilizer.

Typical Alignment Drawing.—Airplane makers furnish users of their planes with what is known as an alignment or rigging plan drawing, such as that shown at Fig. 288 and specific directions are given for such angles as the dihedral, incidence, stagger, etc. The drawings are for the Nieuport scout, an obsolete wartime plane of French design but will be useful in showing how such drawings are prepared. The following instructions accompanied the drawing shown.

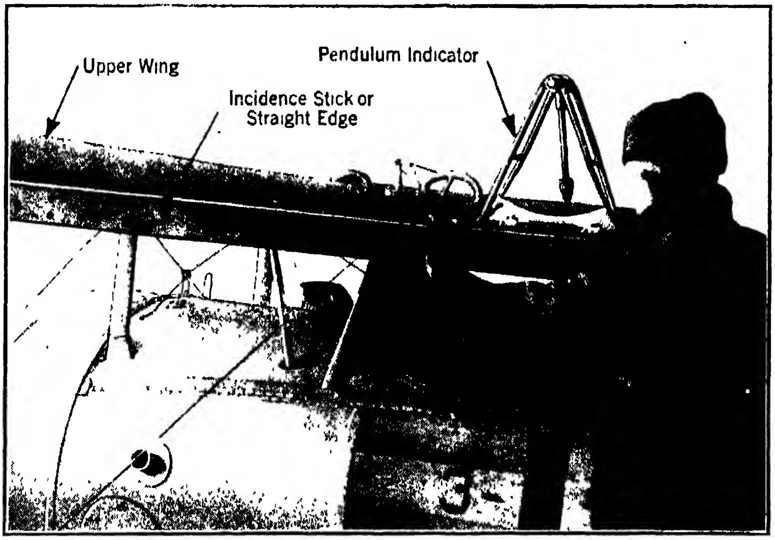


Fig. 287.—How Pendulum Indicator and Straightedge are Used to Check Incidence of Upper Wing.

Flying Position.—The machine is in flying position when the tailplane is level transversely and its center line level. To place in flying position level transversely by spirit level and straightedge placed across the tailplane. Make adjustments by packing blocks under the undercarriage axle. Level longitudinally by setting so that the top surface of the tailplane slopes backwards and downwards at an angle of 10 minutes (one-sixth of a degree). Check by level and straightedge placed longitudinally along the tailplane. Make adjustments by raising or lowering tail.

Truing Up the Fuselage.—Place fuselage on two trestles with top longerons level as far as possible. Working from front to rear, make internal bracing wires equal at each section and check by trammel. Make top cross bracing wires equal in each bay and similarly make bottom cross bracing wires equal in each bay and check by trammel. True up side bracing wires on one side until top longeron on that side is level from No. 2 side strut to tail and the front upper edge of the longeron is 50 m/m below that level. Check by spirit level and long straightedge and true the other side

in the same way. Check for there being no distortion or winding in the fuselage as follows: Place a straightedge transversely across the top longerons immediately in rear of No. 2 side struts. Place another straightedge transversely across the top longerons at any other point. The upper edge of the second straightedge must be in line with the upper edge of the first straightedge. Check by sighting and repeat for other points. A plumb

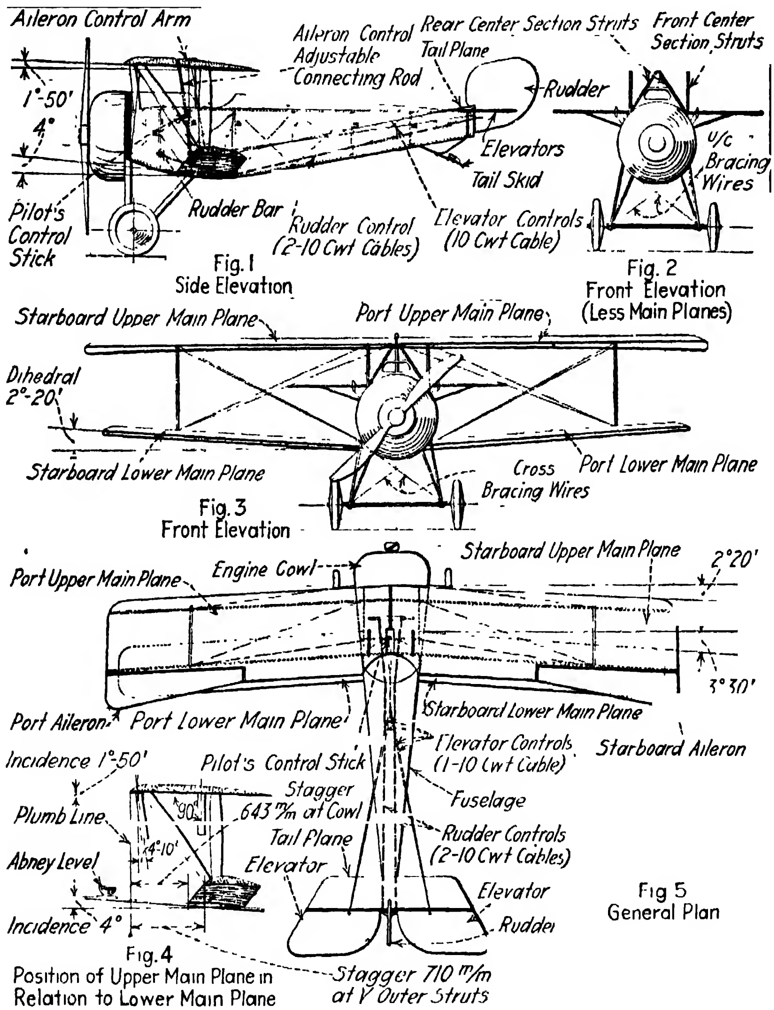


Fig. 288.—Typical Alignment Drawing Giving Complete Instructions for Setting Up Nieuport Scout, a French Wartime Plane.

line dropped from the mid point of a top cross strut must strike the mid point of the corresponding bottom cross strut. Truing Up Undercarriage: The u/c is symmetrical about vertical center line of machine and front struts are vertical viewed from the side with machine in flying position. Adjust front cross bracing wires, making corresponding diagonals equal, check by trammel. Truing Up Center Section Struts: The front center

section struts are vertical viewed from the front and are at an angle of 4.10 degrees to the vertical viewed from the side. Adjust front cross bracing wires making corresponding diagonals equal and check by trammel. The rear center section struts are vertical viewed from the side and allow of no adjustment.

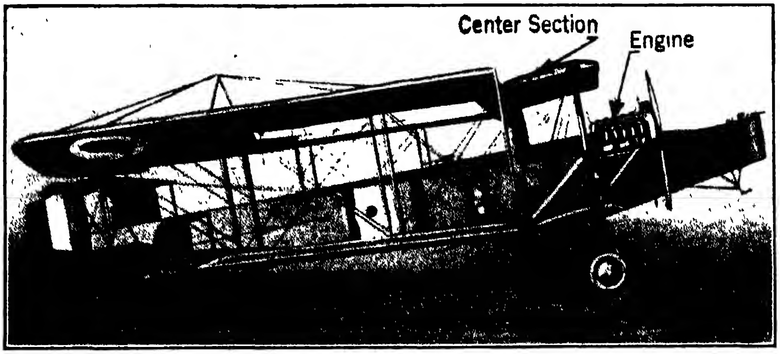


Fig. 289.—How Folding Biplane Cellule Makes Housing of Large Span Airplanes Practical in Smaller Hangars than Would Otherwise be Needed.

Truing Up Main Planes.—The top surface of the upper main planes must be level. Check by placing a long straightedge across the top of the planes and aligning with a straightedge placed across the tailplane. Check for leading edges being square with center line of machine by taking measurements from adjusting collars at bottom of V outer struts to rudder post and propeller boss. Corresponding measurements must be the same on both sides. Stagger: The stagger is 645 m/m at side of cowl, and 710 m/m at outer struts. Check by dropping plumb lines from the leading edge of upper main planes. The horizontal fore-and-aft distance between the

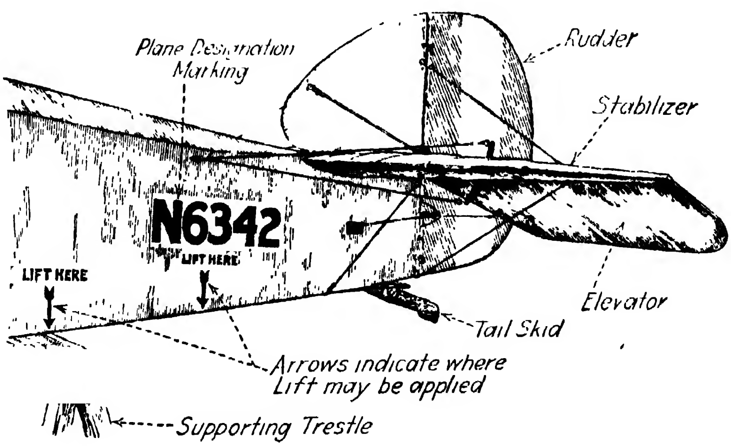


Fig. 290.—Tail of Airplane Showing Arrows Indicating Points where Supports or Lifting may be Applied without Damage to Fuselage.

leading edge of lower main planes and plumb lines must be 645 m/m at side of cowl and 710 m/m at V outer struts. Incidence: The incidence of the upper main planes is 1.50 degrees throughout. The incidence of starboard lower main plane is 4 degrees throughout, and the incidence of port lower main plane is 4 degrees at root and 5 degrees at V outer struts.

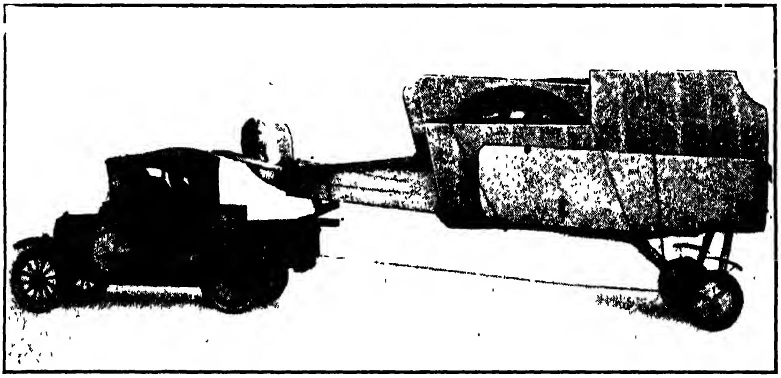


Fig. 291.—Airplane with Wings Removed and Folded Against Fuselage for Road Transportation Behind Towing Car.

Check by Abney level and straightedge, placing latter from leading edge to trailing edge at ribs. Dihedral: The dihedral angle for lower main planes is 2.20 degrees. Check by level and straightedge along the spars.

Empennage.—Tailplane: With machine in flying position the tailplane must be level transversely and its top surface must slope backwards and downwards at an angle of 10 minutes (one-sixth of a degree). Check by level and straightedge. Check for tailplane being square with machine, by taking measurements from adjusting collar at V outer struts to lateral extremities of tailplane rear spar. These measurements must be the same on both sides. Rudder: With rudder bar square in fuselage, rudder must point directly fore-and-aft, and be square with machine. Elevators: With pilot's control stick central or in neutral position, elevators must be in direct continuation of tailplane.

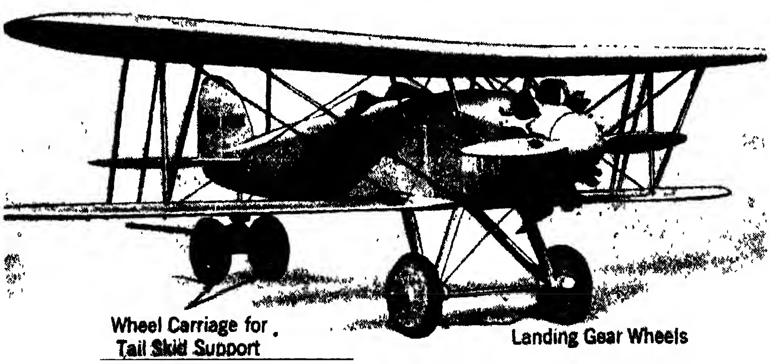


Fig. 293.—Showing Type of Wheeled "Dolly" with Turntable Support to Handle Rear End of Airplanes without Damage.

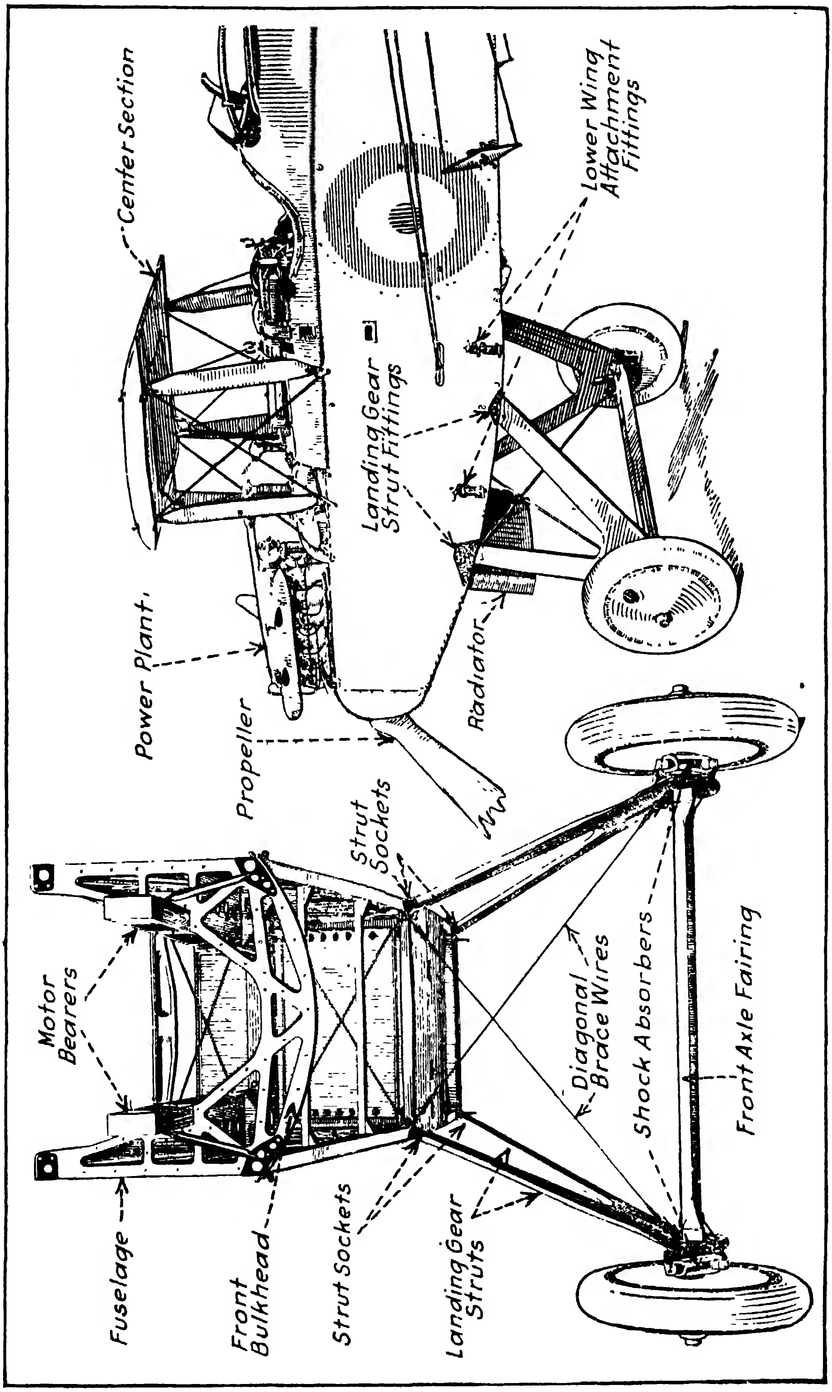


Fig. 292.—Views of Airplane Fuselage Front End Showing Landing Gear Struts, Points of Attachment to Fuselage and Brace Wires, all Points that Must be Considered in Aligning that Structure.

Handling Airplanes.—Considerable care is required in handling an airplane of the usual wood, fabric and wire type when it is on the ground and great care is required when walking on the wings so that no weight will be imposed at points not adequately braced or reinforced to stand it. Large airplanes are generally provided with walkways of veneer over the wings near the fuselage, especially those of the twin motor type where the power plants are carried in the wing cellule and it is necessary to stand on the wing when working on the motors. Some large span airplanes have folding wings, i.e., the biplane wing cellules are hinged to the center section in such a way that the front fastenings are released and the rear attachment members act as hinges on which the wing structure may be swung back against the fuselage, as shown at Fig. 289, which shows an early Handley-Page type bomber. This construction makes it possible to put large planes in ordinary hangars.

Considerable damage may be done to the airplane structure if it is carelessly handled and in jacking them up from the ground. Many airplanes, especially commercial and military types have arrows indicating points where trestles may be placed or where lifting effort may be applied painted at various points as shown at Fig. 290. The general rules to follow are:

(1) Remember that nearly all the wood of the aeroplane is designed to take the stress of direct *compression* and is cannot be safely bent. In packing an airplane up from the ground the packing must be used in such a way as to come underneath the interplane struts and the fuselage struts. Soft padding should always be placed on the points upon which the aeroplane rests.

(2) When pulling the machine along the ground with an automobile as shown at Fig. 291, always, if possible, pull from the undercarriage by supporting the tail skid on the tow car and have a rope extend from the rear of the car to the landing gear axle. If the trip is to be a long one, be sure the tires are well inflated and dismount the wings which are best carried on a separate trailer though on short trips they can be attached to the sides of the fuselage. If necessary to pull from elsewhere then do so by grasping the interplane struts as low down as possible.

(3) As regards handling parts of airplanes. Never lay anything covered with fabric on a concrete floor, as any slight movement will cause the fabric to scrape over the concrete with resultant damage.

(4) Struts, spars, etc., should never be left about the floor, as in such a position they are likely to become damaged, it is necessary to protect the outside fibres of the wood. Remember also that wood easily becomes distorted. This particularly applies to the interplane struts. The best method is to stand them up in as near a vertical position as possible.

Landing Gear Struts.—The undercarriage must be very carefully aligned as shown in the rigging diagram supplied by the maker.

(1) Be very careful to see that the undercarriage struts bed well down into their sockets. If this is not done then after having a few rough landings, they will bed down farther and throw the undercarriage out of alignment, with the result that the machine will not taxi straight. These points

also require careful inspection if the airplane is towed for any distance over a rough field or road.

(2) When rigging the landing gear, the airplane must be packed up in its flying position and sufficiently high so that the wheels are off the ground. When in this position the axle must be horizontal.

(3) Be very careful to see that the shock absorbers are of equal tension, and that the same length of elastic and the same number of turns are used in the case of each absorber.

Two views of a typical landing gear or undercarriage are shown at Fig. 292. When moving an airplane around at a flying field, a two-wheel carriage, called a "dolly" is shown at Fig. 293 is used to carry the tail skid.

QUESTIONS FOR REVIEW

1. Outline principal precautions when unpacking an airplane.
2. Describe steps in assembling airplane.
3. What are the three principal methods of checking dihedral, of checking stagger?
4. How are ailerons rigged in most planes?
5. Describe the string and straightedge method of lining up a truss type fuselage.
6. What is an incidence stick and how is it used?
7. What is a goniometer and how is it used in setting up an airplane?
8. Why is the fuselage placed in its flying position when lining up?
9. Describe "wash-in" and "wash-out," how and why provided.
10. Outline rudder and elevator control adjustments.

CHAPTER XIV

INSPECTION AND MAINTENANCE OF AIRPLANES AND ENGINES

Inspection of Propeller—Inspection of Power Plant—Inspection Routine, Liberty and Similar Engines—Instructions for Starting Liberty Engine—Inspection Routine, Wright Air-Cooled Engines—Daily Inspection—After Twenty Hours Flying—Complete Overhaul—Instructions for Starting and Normal Operation, Wright Radial Air-Cooled Engines—Ground Test of Engine—Flight Test—Landing—Fuels for Wright Engines—Oil for Wright Air-Cooled Engines—Cold Weather Caution—Landing Gear Inspection—Fuselage Nose Parts—Wing Fittings and Struts—Inspecting Ailerons—Inspection of Fuselage Interior—Stabilizers and Control Wires—Cleanliness Important—Weekly Inspection Card—Causes of Airplane Accidents—Recovering Airplane Wings—Patching Sheet Duraluminum—Repairing Tubular Fuselages—Power Plant Troubles—Trying out Ignition System—Common Defects in Fuel Systems—Zenith Carburetor Adjustment—Defects in Oiling Systems—Water-Cooling System Troubles —Radial Air-Cooled Engines —Excessive Oil Temperature.

It is important that all parts of an airplane should be inspected thoroughly before the machine is allowed to leave the ground, and this inspection must be carried on periodically while the machine is in service. The inspection should follow a certain well-devised and logical sequence of events, and should not be done in a haphazard manner. Unless the inspection processes follow logically and in a regular order, the inspectors are very likely to omit some important part that may result in faulty action while in flight. A series of special illustrations which accompany this chapter have been posed by a practical aviator, and are intended to bring out the important points that should receive periodical inspection.

Inspection of Propeller.—The first point that should receive attention is the propeller. It should be carefully examined to determine that the blades are in good condition. This means that they should be clean and well polished, and if provided with copper or cloth tips, these should be securely in place. Any splinters or cracks in the blade may result disastrously; and the propeller should be removed unless both blades are absolutely sound. The hub-assembly and the propeller should be inspected with a view to locating any looseness in the propeller hub bolts, or the nuts and cotter pins. After a propeller has been in use for a time the hub flanges may compress the wood and the propeller be loose in the hub. This condition is easily remedied by screwing down the propeller hub flange retention nuts until the propeller is securely clamped. Another point that should be looked at is the method of holding the propeller to the engine shaft. This may be determined by grasping the propeller firmly and shaking it to see if there is any lost motion between the hub and the shaft. If the hub retention nuts have not been properly applied some looseness is apt to develop after the machine has been in flight. A propeller should fit the engine shaft absolutely tight, because any looseness

will result in injurious vibration. It is presumed that the propeller has been carefully checked for track as described in the Chapter on Propellers.

Inspection of Power Plant—The power plant is the next point which should be thoroughly checked over, and as previously emphasized, the pilot should not accept anybody's opinion that the power plant is in good condition. He should satisfy himself of this before the machine leaves the ground. The radiator and all water connections should be checked over to see that there are no serious water leaks. It is also important that the radiator be full of water. The oil indicator on the side of the crankcase, in some engines, will show the amount of oil there is present in the sump. The external oil lines, particularly those leading to the oil pressure gauge, should be absolutely tight, and all piping that conveys oil must also be examined to see that the joints are securely fastened and that there is no opportunity for loss of lubricant. The fuel system demands a more rigid inspection than either the cooling or oiling systems because a gasoline leak is apt to be the cause of fire and, of course, should be guarded against.

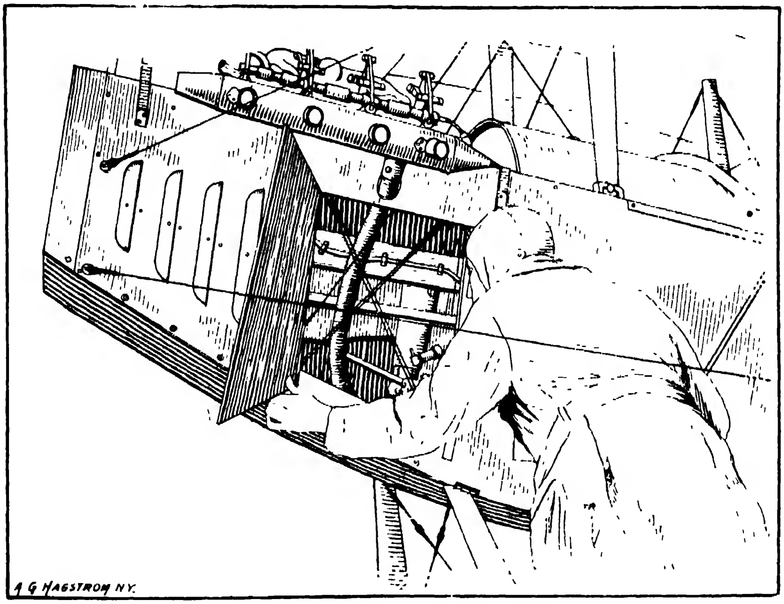


Fig. 294.—Examination of Power Plant Should be Thorough.

The points that should be inspected most carefully are the joints in the pipe line at both fuel tank and carburetor. If a gravity feed system is installed, the inspector should make sure that the vent in the tank filler cap is free and clear so that it will admit air to the tank. If a pressure feed system is fitted it is important that the tank cap and piping conveying air pressure be absolutely tight. The relief check valve should be tested to see if the pressure releases at the proper point. Excessive pressure is apt to result in excessive fuel-consumption. Of course, it is important that the tank be full of gasoline in a gravity system and very nearly full in a pressure system. The hand pump should be tested to make sure that it is in

proper working condition. If a strainer or filtering device is included in the fuel pipe line this should be emptied from time to time to clean out any water or sediment that may be trapped therein.

The engine should be run slowly to make sure that it is firing on all cylinders and then speeded up to be sure that it develops good power. The clearance between the valve operating mechanism and the stems of the intake and exhaust valves should be checked over. All wiring must be clean and the insulation whole. It is important that all connections be tight. The grounding switch for cutting out the magneto should be tested to make sure that it functions properly. The rod or wire connection going from the hand throttle lever to the throttle of the carburetor should be inspected as, if it should become loose in flight, the throttle might jar closed and seriously impair the power production of the engine. Both magneto and carburetor should be firmly attached, the former to the bracket of the engine base, the latter to the induction manifold. The oil pressure should be carefully watched to make sure that it is sufficient for the engine in question. Oil pressures will vary from twenty to 100 pounds, depending upon the design and type of the engine.

When examining the power plant, especial attention must be directed to the parts of the magneto that have to do with the timing and distribution of the ignition current. This means that the distance between the breaker points should be checked to make sure that it is adequate and it is well to remove the distributor board to examine the contact brushes and the current distributing segments if there is any tendency for the engine to misfire slightly.

Inspection Routine—Liberty and Similar Engines.—To insure water-cooled engines rendering the maximum service they must be inspected daily or at least after every five hours of flight. It is advisable that these inspections be systematically carried out and that the inspector be provided with a form covering the points set forth in the following routine. Inspectors should be instructed to rigidly adhere to this form and check the different items off as they are attended to.

1. Feel all bearings—see that they are not overheated.
2. See that propeller hub bolts are tight and properly cotter pinned or wired. It is advisable, after every long flight (five hours) to take the cotter pins or lock wires out of these bolts and draw them up as much as possible. New cotters or lock wires should then be fitted.
3. Check pitch and track of propeller.
4. See that propeller hub is drawn up snugly on shaft.
5. Be sure that propeller hub nuts are securely locked.
6. See that all other visible bolts and nuts are tight and properly locked.
7. Examine all valve springs carefully.
8. Squirt a little light oil through the valve springs onto each valve stem.
9. Examine throttle, spark and altitude adjustment controls. Be sure that they work freely, permit full throw of throttles and distributors that have not become excessively loose.

10. Test all cylinders for compression.
11. Try rocker arms—they should all be free when the valves which they operate are seated.
12. Check tappet gap of all valves—piston at firing point.
13. Check valve timing with timing disc.

Cooling System

14. Examine radiator, water piping, pump, water jackets and all connections for leaks.
15. Fill cooling system.

    Note—If temperature is below freezing, follow Cold Weather Instructions.

Gasoline System

16. Examine tanks, trap, piping and all connections for leaks.
17. Drain water trap.
18. Fill gasoline tank.

Oiling System

19. Drain system by taking out plug.
20. Remove rear pump cover plate which will release oil pump screen
21. Clean screen thoroughly with a brush and gasoline.
22. Replace screen and cover plate using a **new** gasket if the old one was damaged in removing cover.
23. Examine reservoir, cooler and all piping and connections for leaks.
24. Oil thrust bearing.
25. **Replace all hose connections, either for water, oil or gasoline, which show any signs of deterioration.**

Electrical Equipment

26. Examine all electrical connections at generator, regulator, switch, battery and distributor to see that they are clean and tight.
27. Examine all wiring to see that insulation has not become abraded.
28. Clean distributors.
29. Oil generator and tachometer drive.
30. Examine plugs for cracked or loose porcelains. This should preferably be done immediately after the engine is stopped and while the plugs are still hot.
31. Check contact breaker clearance and examine contact points.
32. Check timing of ignition and synchronization of distributors.

    Caution—Leave the ignition switches and the gasoline shut-off cock in the "Off" position.

If the switches are left "on," the battery will discharge through the Ignition System and generator and it will be necessary to either recharge or replace it before the engine can be started again. With both switches turned off, the ammeter needle should stand approximately at zero.

Cold Weather Suggestions

1. Inspect the engine carefully as instructed.
2. Put three gallons of **hot** lubricating oil into the engine crankcase. Oil should be heated in an open top container set into boiling water.
3. Put a sufficient quantity of **hot** oil into the oil reservoir so that the reservoir will be about two-thirds full after the three gallons placed in the crankcase have been pumped back into it.
4. Remove the Vent Plug in the side of the oil pump body so that the hot oil may run in to prime the pump.
5. Fill the cooling system with **boiling** water. Soft water should be used wherever available. **Do not use** any anti-freeze preparation containing calcium-chloride though glycerine and alcohol solutions may be used.
6. Prime the engine and start at slow speed with the throttle partially closed.
7. Accelerate and slow down the engine occasionally to throw the oil up into the cylinders. Run the engine on the ground until the oil has been thoroughly distributed as indicated by the action of the oil pressure gauge and a uniform temperature of the engine. This period need not be continuous and if possible engines should be alternately run for a few minutes, stopped for five minutes and then re-started.
8. **Do not attempt to get off the ground** until the water temperature is at least 160 degrees fahrenheit.
9. If the machine is not to leave the ground at once, the engine should not be allowed to remain stationary for more than ten minutes at a time as it will get cold again.
10. After finishing a test or flight, **drain all oil and water before the engine has had an opportunity to cool off.** Crankcase drain plug and sump cover should be removed to drain the oil from the engine. A plug of the same type is provided in the bottom of the water pump for the purpose of draining the water. If the engine is installed as a tractor, this plug will be the lowest point in the cooling system. If the engine is installed as a pusher, the tail of the machine should be raised until the propeller end of the engine is higher than the distributor end in order to allow all of the water to drain off.
11. Spark plugs should be removed from the engine and kept in a warm place if the engine is to stand idle over-night or for any considerable period.

Instructions for Starting Engine.—Before starting a new engine or one which has stood idle for some length of time, it is advisable to inject a small quantity of lubricating oil (about one-half ounce) through each priming cock. With the ignition switches "Off," turn the propeller forward through five or six revolutions to distribute the oil over the cylinder walls.

Block Wheels Securely.

Set throttle just slightly open, in other words, at a point which will run the engine at 600 to 800 r.p.m.

Set spark at fully retarded position.

The ignition system for Liberty engines is so designed as to absolutely prevent the production of a spark when turned backward, nor will the engine "kick back" if it should happen to "rock" after cranking. However, it is essential that the spark be **retarded** when cranking.

Prime engine by injecting a small quantity (fill priming cock twice) of gasoline through each priming cock. In cold weather it will be necessary to prime the engine a little more heavily than in warm weather. It is better, however, to insufficiently prime it than to prime it too heavily.

With the ignition switch still **"off"** turn engine forward two revolutions.

Turn one (either one) ignition switch **"on"** and start engine by pulling steadily down on the propeller blade and at the same time away from it. The switch is so designed that, with both switches turned **"on,"** the generator is connected in, which will result in a rather high rate of discharge from the battery and possible difficulty in starting. Both switches should be turned **"on,"** however, as soon as the engine is running.

As soon as the engine is started, advance the spark about half way, leaving the throttle in approximately the starting position, and allow the engine to run at idling speed (about 800 r.p.m.) for five to ten minutes or until it is thoroughly warmed up. At the same time test crankcase temperature with your hand. The crankcase should be warm by the time the temperature of the water has increased to 150 degrees fahrenheit.

Accelerate and slow down the engine occasionally to throw the oil up into the cylinders. In extremely cold weather it is possible that the cooling water might warm up more rapidly than the lubricating oil. In this case it would be advisable to stop the engine for a few moments in order to allow the heat from the cylinders to travel down to the crankcase.

In the meantime—

Note the Oil Gauge pressure. After about three minutes running at 600 to 800 r.p.m. this should show above five pounds pressure, and at 1,600 r.p.m. up to thirty pounds maximum. Failure to show these pressures may be due to dirt on the relief valve seat. The gauge will show higher pressures when the engine is first started and is cold than after it has thoroughly warmed up.

Examine all oil piping for leaks.

Note Air Pressure Gauge. The engine-driven air pump with its regulator, is designed to hold the pressure on the gasoline tank at approximately three pounds. In order to determine whether or not the pump is functioning properly, screw **down** the pressure regulator adjusting screw. This should cause the pressure in the tank to rise if the pump is operating as it should. Now screw the regulator adjustment **up** until the pressure is held steadily at three to four pounds.

Note Water Circulation. Temperature gauge should show a steady rise up to not **to exceed 200 degrees** fahrenheit. The most efficient temperature will vary with weather conditions, but will average 180 degrees fahrenheit.

Note Ammeter Reading. At idling speeds the ammeter needle will stand on the "Discharge" side of zero. At about 650 r.p.m. with both

switches "on," the needle will stand at zero and at high speeds it should stand on the "Charge" side of zero. (See Chapter on Ignition System.)

When the engine is well warmed up, the throttle may be opened wide (wheels blocked) and the speed of the engine noted. Tachometer should show 1,550 to 1,600 r.p.m. on the ground.

Operation of each ignition head should be tested separately by shutting off first one switch and then the other. The engine should show the same r.p.m. in each case. With the throttle wide open, whether the engine is running on one or both sets will make very little difference in the speed (possible 10 or 15 r.p.m.). At lower speeds (600 to 800 r.p.m.) the effect will be more apparent.

Before stopping the engine, throttle it down to idling speed for a minute or two, then turn the ignition switches to "off" and at the same time open the throttle wide. Opening the throttle will "choke" the engine and cause it to stop immediately. Allowing the throttle to remain in the idling position may permit an overheated plug or particle of carbon to fire the engine spasmodically for some time after the ignition is cut off.

Caution—Do not attempt to crank an engine immediately after it has been stopped. An overheated plug or incandescent particle of carbon might cause pre-ignition and a disastrous back kick. Allow it to cool off for a few minutes.

Inspection Routine—Wright Air-Cooled Engines.—In order to obtain maximum reliability and service from Whirlwind engines a regular schedule of inspections and overhauls should be maintained. Serious failures very often arise from minor causes which a few minutes inspection could have averted. The following schedule is suggested in the instruction book issued by the Wright Aeronautical Corporation.

Daily Inspection: Every flying day the following inspection should be made. Check all cylinders, one at a time in firing order (1, 3, 5, 7, 9, 2, 4, 6, 8), as follows:

Models J-4A and J-4B

1. Does clearance between rocker roller and valve stem, on compression stroke, seem normal?
2. Are rockers free on shafts and lock wires secure?
3. Are rocker rollers free and lock wires secure?
4. Are valves free in guides?
5. Are valve springs and valve spring retainers intact?
6. Are rocker support lock nuts tight and are rocker rollers central on valve stems?
7. Are spark plugs tight?
8. Grease rocker shaft with Alemite gun using automobile transmission oil.
9. Oil rocker rollers with engine oil.
10. Are ignition terminals secure to wires and plugs and is insulation on wires intact?
11. Is compression normal?

After all cylinders have been checked proceed as follows:

12. Are carburetor and carburetor manifold tight at securing flanges?
13. Are fuel tanks filled?
14. Is oil tank filled?
15. Are magneto ground wires secure?
16. Are throttle, mixture and magneto controls free throughout their range?
17. What is full throttle r.p.m.?
18. Is engine operation good on either magneto?
19. What are oil pressure and temperature? Oil pressure should be 50 to 75 pounds per square inch and oil outlet temperature not over 180 degrees fahrenheit or 82 degrees centigrade scale.
20. What is gasoline pressure? (Should be 2-4 pounds per square inch.)

Model J-5

The daily inspection of the Model J-5 engine should include items 7, 8 and 10 to 20 inclusive.

Twenty Hours. After every twenty hours of flight the valve gear should be disassembled and inspected as follows:

Models J-4A and J-4B

1. Remove push rods and examine balls and ball sockets for wear.
2. Grease sockets in rockers.
3. Thrust lower ball ends of push rods in can of heavy grease and replace the rods in their proper sockets.
4. Make complete inspection as outlined for each flying day.

Model J-5

1. Remove the rocker box covers and make a check of the amount of motion of the various parts. If the tappet clearance seems normal it should not be disturbed. If any part seems to have too much motion, or if the tappet clearance is excessive, the rocker arm and push rod should be removed and the cause determined. Check the offending part against the maximum allowable clearance as indicated in charts furnished by the manufacturers to users of its product and replace if this is exceeded or if in the opinion of the operator it seems advisable.

After the valve gear has been inspected, repaired and reassembled the following items should be checked (all "J" series models except as noted):

1. On J-4 series engines check clearance between rocker rollers and valve stems with feeler and reset to .010. Be sure adjusting ball and lock nuts are tight.
2. Are spark plug points clean and are gaps set at proper clearance (.020 of an inch to .025 of an inch for A. C. Plugs; .015 of an inch for B. G. Plugs).
3. Are nuts on inlet pipe upper flanges tight?
4. Are inlet pipe packing nuts tight?

5. Are cylinder hold down nuts tight?
6. Are fuel strainers clean?
7. Are fuel lines and connections secure and free from leaks?
8. Is lock on gasoline pump pressure adjusting screw secure?
9. Are oil strainers clean?
10. Drain the old oil from the tanks and lines and flush with kerosene until perfectly clean. (Do not use kerosene inside the engine.) Replace the lines and put two gallons of clean oil in the tank. Run the engine for twenty minutes and then drain out all the oil again. Replace the lines and fill the tank with clean oil. Great care should be taken to see that all the oil lines are replaced properly and there are no air leaks. Small air leaks are apt to interfere seriously with the proper functioning of the lubricating system.
11. Oil tanks should be drained and filled with fresh oil.
12. See that hand turning gear is well lubricated.
13. Are engine mounting bolts tight?
14. Does each magneto get full advance when operated from cockpit?
15. Are magneto breaker points clean and gaps set at .012 of an inch?
16. Are magneto couplings in good condition?
17. Put four drops of medium machine oil in rear magneto oil holes. Fill front holes.
18. Are propeller hub lock nuts and propeller hub bolts tight?
19. Check the clearance between the rear of the rocker boxes and the cylinder heads and make sure it is .031 of an inch (Engine cold). While this dimension should not vary it is extremely important and should be checked carefully. Incorrect clearance is very apt to result in failure of the rocker box studs.

It is advisable to run the engine at part throttle for at least one-quarter or one-half hour twice a week in order to keep interior parts flushed with oil. This will prevent the vapor due to condensation in the crankcase from rusting steel parts.

Complete Overhaul.—It is suggested that the compression, as noted in Item 11 of the daily inspection, be checked very carefully on each cylinder. As soon as one is found to be low it should be removed, the valves tested for leakage and the piston rings checked for tension. The valves should be ground and the piston rings replaced when necessary. In this manner the engine can be kept up to power and speed. It is sometimes very difficult to distinguish between a valve which is leaking and one which is being held open by a bit of dirt or carbon on the seat. The only way to check this out is to run the engine for several minutes and then try the compression again. Experience with "Whirlwind" engines in service has indicated that the length of the period between overhauls is limited by the tendency of the lubricating system to fill up with sludge. This is composed of gums formed in burning the lubricating oil, carbon, lint and substances taken into the engine through the carburetor or breathers. After 200 hours of service the accumulation is likely to become severe enough to plug up one of the passages resulting in the seizure of the bearing whose

oil supply is cut off. It is therefore recommended that "Whirlwind" engines be given a complete overhaul after every 200 hours of service.

Instructions for Starting and Normal Operation.—Before starting Wright radial air-cooled engine for the first time the following items should be checked:

1. Check over all nuts and bolts both on the engine and the mount and see that they are tight and properly locked.
2. Check the propeller hub nuts to be sure they are tight and cottered.
3. Lubricate the valve gear with Alemite gun using 600W oil.
4. Fill the oil tank with an ample quantity of oil for the run (minimum quantity 2 gallons) and see that all lines are open.
5. Fill the gasoline tank with the proper grade of gasoline.
6. Operate the throttle and mixture controls and inspect the levers on the carburetor to make sure that they hit the stop on both ends of the travel without restriction.
7. Operate the spark advance control and inspect for full operation of the lever.
8. See that the tachometer and pressure gauge are properly connected and that the oil temperature thermometer bulb is in place.
9. Turn the engine over by hand to see that everything is clear.
10. See that the priming line and pump are properly connected and in working order.
11. Open the cocks in the gas line and operate the hand pump if supplied. See that gasoline is supplied to the carburetor and that all lines are tight. See that the carburetor does not drip gas.
12. See that ground wires are connected to the magnetos.

Starting. Having completed the pre-starting inspection the engine is ready to start and should be handled as follows:

1. Give the engine several strokes of the priming pump. Experience is necessary to determine the proper amount of prime for each engine. About five or six strokes of the Lunkenheimer pump are usually necessary. Excessive priming has a tendency to wash the oil off the cylinder walls and cause scoring or seizing of the sleeves and pistons.
   In cold weather the engine requires more priming than in warm weather.
   A hot engine does not ordinarily require priming.
2. Turn the engine over a number of times with the throttle closed to suck the gas into the cylinders.
3. Set the throttle to approximately ⅛ open and the mixture to full rich. Easier starting will be obtained with spark control at approximately full advance.
4. Operate the starter and allow the engine to turn over a full revolution. Then turn the ignition switch to the start position and operate the booster if one is being used.
5. If the engine fails to start after several attempts prime again and

repeat. If the engine is overprimed the throttle should be opened wide and the engine turned backward several revolutions by hand. Be sure the ignition switch is off.

6. In extreme cold weather the oil should be heated before filling the oil tank.

If the engine fails to start after a reasonable number of attempts, consult data on troubles to ascertain possible cause.

Ground Test. When the engine starts the spark should be advanced, the throttle pulled back to 600 or 800 r.p.m. and the gauge watched for oil pressure. If the oil pressure fails to rise within one minute the engine should be shut down and an investigation made. After the gauge indicates oil pressure the engine should be run at 600 to 800 r.p.m. for 2 minutes or more and the throttle then opened to 1,000 r.p.m., where it should be held until the oil outlet temperature starts to rise. The speed may then be increased slowly to full throttle. The mixture control should be leaned out until the engine is turning maximum r.p.m. This may occur in the full rich position. Observe the r.p.m., oil pressure and oil temperature. With the mixture control set for maximum r.p.m., check the functioning of the engine when running on one magneto at a time. If the values observed are normal and the speed does not drop more than 75 r.p.m. on each magneto the engine is ready to fly. It should be remembered that the engine receives very poor cooling while on the ground and prolonged running at full throttle should be avoided.

Flight. The instruments should be noted at frequent intervals to see that the power plant is functioning properly. The engine should be operated to keep within the following limits:

Oil pressure 50 to 75 pounds per square inch.
Outlet temperature not over 180 degrees fahrenheit (82 degrees centigrade.)
Fuel pressure 2 to 4 pounds per square inch.

If the oil pressure falls below 35 pounds an immediate landing should be made and the cause of the trouble located and removed. It is not so serious when the oil pressure exceeds the high limit but it should be corrected at the end of the flight. This can generally be done by adjusting the relief valve.

High oil temperature when not caused by atmospheric conditions may be a sign of trouble in the engine. If the outlet oil temperature rises above 180 degrees fahrenheit a landing should be made as soon as possible and its cause determined and corrected.

Landing. Because of the faster heating and cooling rate of air-cooled engines a hot engine should never be shut down rapidly, except in emergencies, as this is almost sure to warp the valves. After a plane has landed and taxied to the line, the spark should be retarded, the throttle slowly closed to 600-700 r.p.m., and the gasoline supply shut off. The engine should be allowed to run this way until the fuel supply fails. If this is done regularly the time between overhauls will be greatly increased.

Fuels. The fuel used should be either of the type known as Grade B domestic aviation gasoline or one of the commercial fuels recommended. The use of other fuels is apt to lead to unsatisfactory operation and serious

damage to the engine. The manufacturer will assume no responsibility for the engine's performance when other fuels are used.

In case of emergency, when approved gasoline is not available, benzol gas, ethyl gas or high test automobile gasoline should be used. The engine should then be operated at reduced throttle with the mixture control in the full rich position. Gasoline from California base crudes is much superior to gasoline from the mid-continent and eastern crudes.

The following specification corresponds to the Navy Department Specification No. 7G1 B of December 1, 1924, for Grade B domestic aviation gasoline.

Grade B, domestic aviation gasoline shall conform to the following requirements:

1. The gasoline shall be free from water and suspended matter.
2. Color.—The color shall not be darker than No. 25 Saybolt.
3. Doctor test.—The doctor test shall be negative.
4. Corrosion test.—One hundred c. c. of the gasoline shall cause no gray or black corrosion and the amount of deposit when evaporated in a polished copper dish shall not exceed 3 mg.
5. Distillation range.—The temperature limits are as follows: When 5 per cent of the sample has been recovered in the graduated receiver, the thermometer shall not read more than 75 degrees centigrade (167 degrees fahrenheit), or less than 50 degrees centigrade (122 degrees fahrenheit).

   When 50 per cent has been recovered in the receiver, the thermometer shall not read more than 105 degrees centigrade (221 degrees fahrenheit).

   When 90 per cent has been recovered in the receiver, the thermometer shall not read more than 155 degrees centigrade (311 degrees fahrenheit).

   When 90 per cent has been recovered in the receiver, the thermometer shall not read more than 175 degrees centigrade (347 degrees fahrenheit).

   The end point shall not be higher than 190 degrees centigrade (374 degrees fahrenheit).

   At least 96 per cent shall be recovered as distillate in the receiver from the distillation.

   The distillation loss shall not exceed 2 per cent when the residue in the flask is cooled and added to the distillate in the receiver.
6. Acidity.—The residue remaining in the flask after the distillation is completed shall not show an acid reaction.
7. Sulphur shall not be over 0.10 per cent.

Oil. Lubricating oils for use in Wright engines must conform to the following specification:

1. Flash point—Method 110.31. The flash point shall not be lower than 400 degrees fahrenheit.
2. Viscosity—Method 30.4. The viscosity for summer use shall be 90 to 105 sec. and for winter use shall be 75 to 85 sec.

3. Pour points—Method 20.11. The pour point for summer use shall be less than 45 degrees fahrenheit and for winter use shall be less than 15 degrees fahrenheit.
4. Acidity—Method 510.3. Not more than 0.10 mg. of potassium hydroxide shall be required to neutralize 1 gram of oil.
5. Emulsion test—Method 500.11. The oil shall separate completely in one hour from an emulsion with distilled water at a temperature of 180 degrees fahrenheit.
6. Carbon residue—Method 500.11. The carbon residue shall not exceed 2.5 per cent.
7. Precipitation number—Method 310.1. The precipitation number shall not be greater than 0.5.
8. The oil shall be derived from a petroleum base and shall be free from fatty oils, resins, soap and other compounds not derived from petroleums.

Tests—All tests shall be made in accordance with "Method for Testing Lubricants and Liquid Fuel" contained in Technical Paper No. 323A, Bureau of Mines. The method numbers given above refer to this paper. Copies of this paper may be obtained upon application to the Quartermaster General, U. S. Army.

Cold Weather Cautions.—Under unusual weather conditions it may become necessary to adopt some method of heating the air entering the carburetor to prevent the formation of ice at the chokes. Wright Air Heaters No. 13732 (J-4B) and No. 13828 (J-5) have been found very satisfactory for this purpose. Due to the wide variation in engine installation requirements these heaters are furnished without pipe connections. In extremely cold weather it will be necessary to preheat the oil before starting. A great deal of time can be saved by draining the oil from the tanks as soon as operations for the day are concluded and before the oil has cooled off. If left in the tank over night it may become so viscous as to require considerable time to drain off. In cold weather it is also advisable to have some sort of lagging on all the external oil lines, especially the drain from the intermediate section to the sump. This will result in higher oil temperature at cruising speed and will decrease the danger of stoppage due to congealed oil. A layer of asbestos cord, shellacked and then wrapped with friction tape provides very good insulation. Lacking asbestos, several layers of ordinary packing cord can be used.

Landing Gear Inspection.—While at the front end of the airplane the next logical point to inspect will be the landing gear. The point that should receive attention first is the tension of the bracing wires that run from the fuselage longerons to the landing gear strut fittings. Next, the attachment of the wiring to the eyebolts in the landing gear and the security wiring on the turnbuckles. All the nuts and bolts on the strut sockets should be examined to make sure that none of the nuts have loosened up, and that all the cotter pins are in place. Examine the wheels to see that there are no loose or broken spokes and that the wheels run true. See that the tires are properly inflated and make sure that they have no

weak spots or cuts in the casing that might result in a blow-out when landing.

The wheels should be tested to make sure that they run freely on the axle and the lock member holding the wheel in place on the axle should be inspected to make sure that it is securely in place. The shock-absorber rubber should be wound evenly and have the proper tension and should be clean. In some types of airplanes, the oil will drip from the engine compartment and flood over the rubber shock absorbers, which produces the rotting effect on the cable, thereby weakening it and resulting in premature depreciation. The wooden fairing on the axle should be inspected to make sure that it is not cracked or split and that there are no splintered

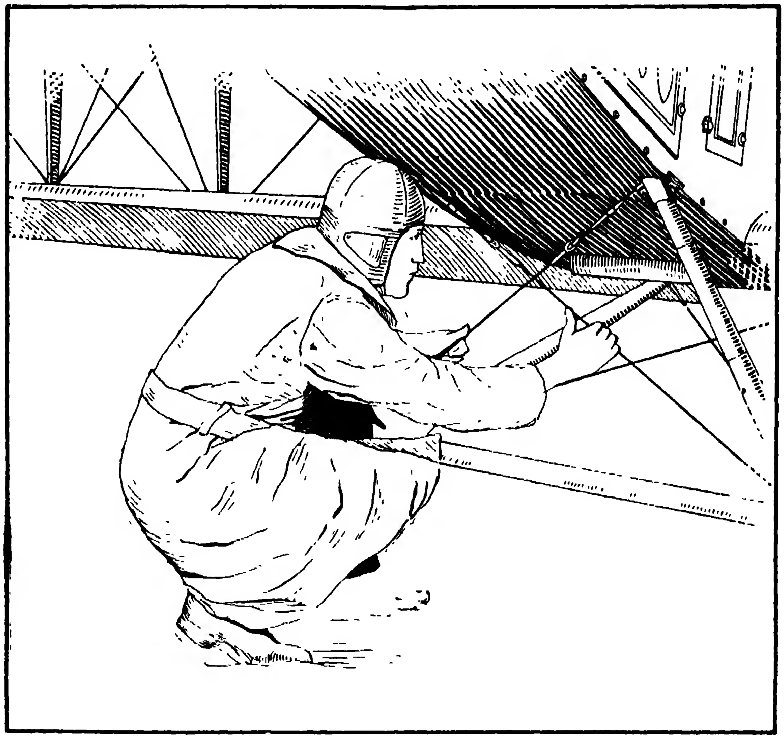


Fig. 295.—Examining Landing Gear Bracing Wires.

pieces projecting from it. Especial care should be taken in inspection of shock absorbers of the enclosed type and the casings should be removed from time to time to check the condition of the rubber parts.

Fuselage Nose Parts.—While at the front end of the machine, examine carefully the front end of the fuselage to make sure that the radiator is properly secured to the carrier plate and that the carrier or nose plate is properly secured to the front end of the fuselage longerons. The engine bed and engine retaining bolts should be examined to make sure that all parts are held tight. The wire braces in the fuselage should be examined with special care in the front compartment, as considerable strength is imparted to the engine carrying portion of the fuselage by these wires.

They should be tight and the turnbuckles should be well safety wired. Another point at the fuselage nose is the anchorage of the wind drag bracing, or the drift wires as they are called. Two of these are found on each side of some types of airplanes, one leading to the lower wing, the other to the upper wing. The soldered ends of these wires should be examined to see that the retention fittings are in the proper tension. Another point that demands inspection is the fastening of the motor compartment cowls and the motor hood cover. These must be secured and all screws that hold them to the fuselage should be in place. Special care is needed in examining any inspection doors in the motor compartments, as these are apt to be left unsecurely fastened and on some types of machines may open up and shake around when the machine is flying.

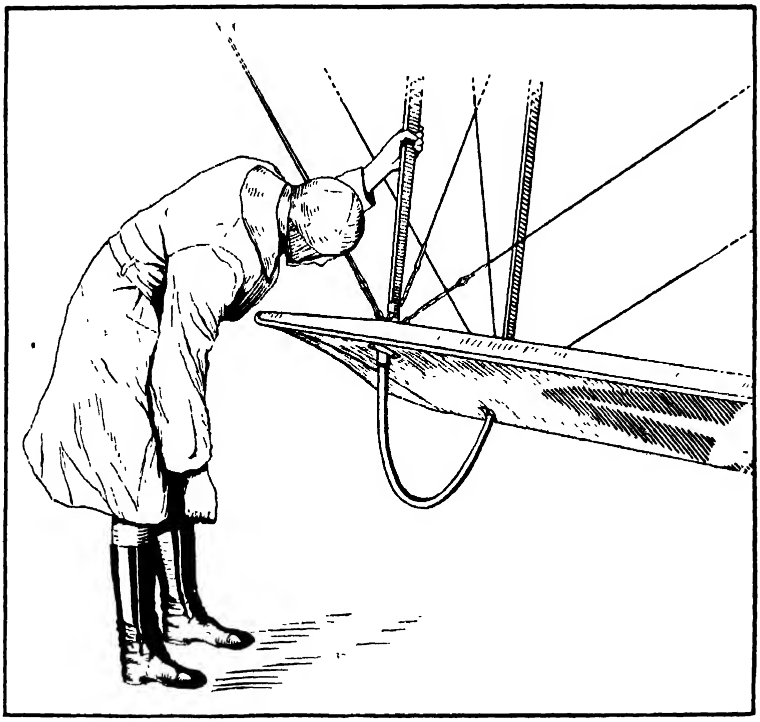


Fig. 296.—Examining Wing Fitting and Landing and Flying Wires.

Wing Fittings and Struts.—The next points to examine are the wing panels and the points of attachment to the fuselage. The best method of doing this is to examine completely the wing panels on one part of the machine before taking those on the other side. There are four points of attachment for the wings on each side of the fuselage, two for the upper wing and two for the lower. The wing fitting pins should be in place and properly cottered and safety wired. When this point has been checked off, the flying wires should be examined, one after the other. On those types of machines where double flying wires are used, it is imperative that equal attention be paid to each wire. The wires should not only have the

required tension, but should not be so tight that the struts between the wings are bowed. The struts should be good, clear wood and have no knots or curly grains. After the flying wires have been checked over, the landing wires which are the single cables should be inspected. While these are not as important as the flying wires, at the same time they should have the proper attention and all fittings should be secured. All wires and turnbuckles should be cleaned and greased with graphite and hard grease to prevent all chance of rusting. The wing fittings at the base of all the struts should show no signs of distortion, and any extending tongues to which bracing wiring is attached should not be bent in such a way that the wire cannot exert a straight pull. The bolts going through the sockets

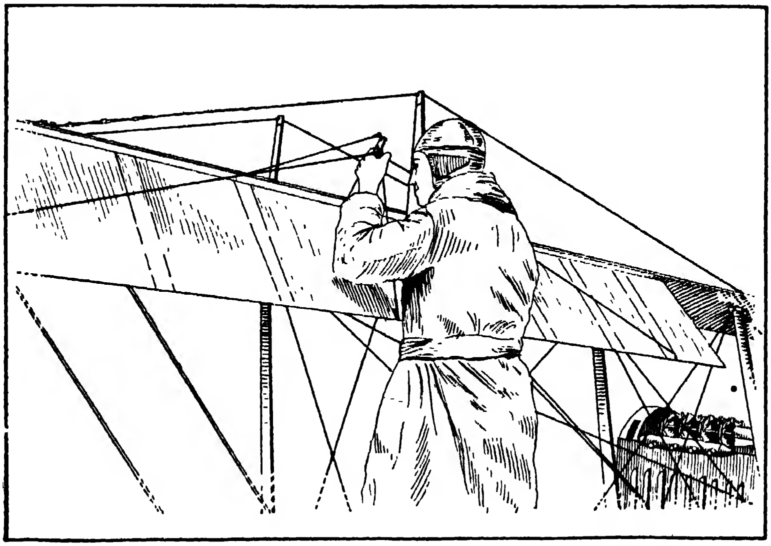


Fig. 297.—Looking over Top Control Horn on Aileron.

at the base of the struts and through the wing fittings should be properly tightened, and the nut on each bolt should be retained with a cotter pin. The struts should not be loose in the wing fittings. This can be ascertained by hitting the side of the strut a sharp blow with the open hand at a point near the fitting. Any lost motion or looseness will be made evident by a clicking noise at the fitting. The incidence wires should be tight, as well as the landing and flying wires. These are the wires that go from the top of a pair to the bottom of the other of the same pair and are clearly shown in Fig. 266 in preceding chapter.

Inspecting Ailerons.—An important member of the control system that should be inspected as part of the wing panel is the aileron or balancing flap. This should be easily operated and should not be distorted or bent in any way. The various points of the hinge assembly should be gone over to make sure that the pins are not unduly worn and that they are securely fastened. A few drops of oil should be applied to the hinges periodically and if the aileron is removed for any reason, oil and graphite should be introduced between the hinge pin and its bearing. The control wire con-

nections at the control wire, or pylon, should be checked over one by one to insure that all clevise pins are properly fitted and that the wire ends leading to the clevises have secure joints. Special attention should be paid to control wires as if these are frayed at any point they should be replaced at once. The pulleys over which control wires run should be inspected for cracks and should be greased to make sure that they will be free running. All ailerons are checked in turn. On some types of machines but two ailerons are used, one on each top wing, while on others four are provided, one on each wing tip.

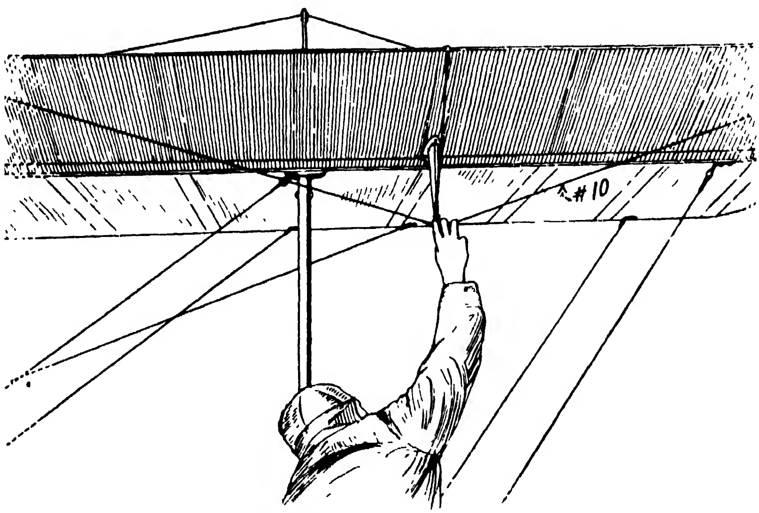


Fig. 298.—Inspecting Lower Control Horn on Aileron.

Inspecting Fuselage Interior.—Before working down to the empennage, or tail of the machine, the cover should be taken off of the fuselage and the various wires used for bracing or control purposes should be checked over to see that they are at the required degrees of tautness, that none of the fittings are cracked or broken, and that all turnbuckles are properly safety wired throughout the fuselage. The inspection of the fuselage is an especially important matter in event of the machine having made a rough landing, or having been in use on service that required frequent "taking offs" and landings as instructions at an aviation school. A rough landing is very apt to loosen up the brace wires in the fuselage, especially if a tail-low landing is made and the strain is taken by the tail skid before the wheels touch the ground.

Stabilizers and Control Wires.—In examining the horizontal stabilizer, the only points that demand special attention are the bolts that hold it in place on the fuselage and also the braces that extend from each side of the rudder posts to the under side of the stabilizer. In examining the elevators, the hinge assembly by which they are attached to the rear end of

the horizontal stabilizer and the control horn should be gone over carefully. The same applies to the rudder, only in this case the hinge assembly is attached to the rudder post at the rear end of the fuselage. What has been said in regard to the bearing points and control wires of the other control surfaces apply just as well to those of the rudder.

Just ahead of the rudder a vertical stabilizer fin is installed. The only points about this that demand attention are the bracing wires and the bolts and nuts by which these are fastened to the horizontal stabilizer. While at the rear end of the machine the tail skid should be looked over with

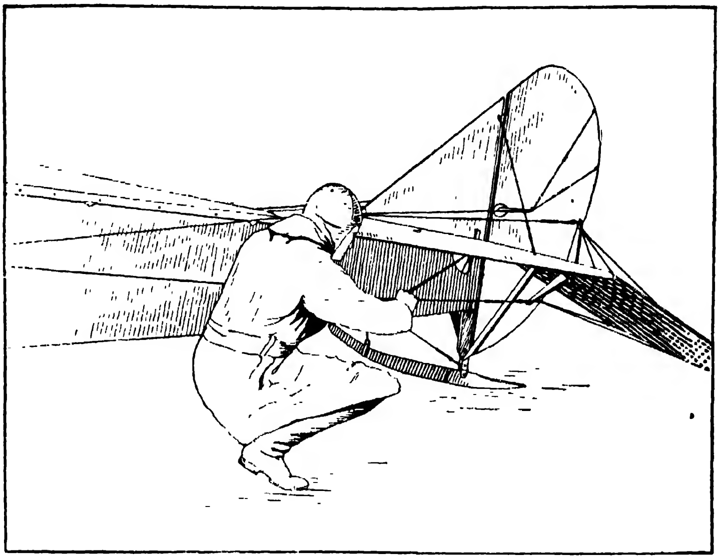


Fig. 299.—Examining Control Wires.

special reference to the supporting hinge or swivel which is attached to the tail post of the fuselage, also to make sure that the wood is not cracked or splintered. The tail skids of most airplanes are provided with a removable shoe of steel which forms a rubbing surface when the tail skid tracks on the ground, as in flying or "taxiing." As soon as this shoe shows signs of wear it should be removed and replaced with a new one, as this will save the tail skid and is much easier to do than replacing an entire tail skid member. Special attention should be paid to the shock absorber rubber of the tail skid.

After every flight pass your hand over the control wires and carefully examine them near pulleys. If only one strand is broken the wire must be changed. Don't forget the aileron balance wire on the top plane. Once a day try the tension of the control wires by smartly moving the control levers about as explained elsewhere. See that all wires are kept well greased or oiled, and that they are all in the same tension. When examining your wires be sure to have the machine on level ground as otherwise it may get twisted, throwing some wires into undue tension and slacken-

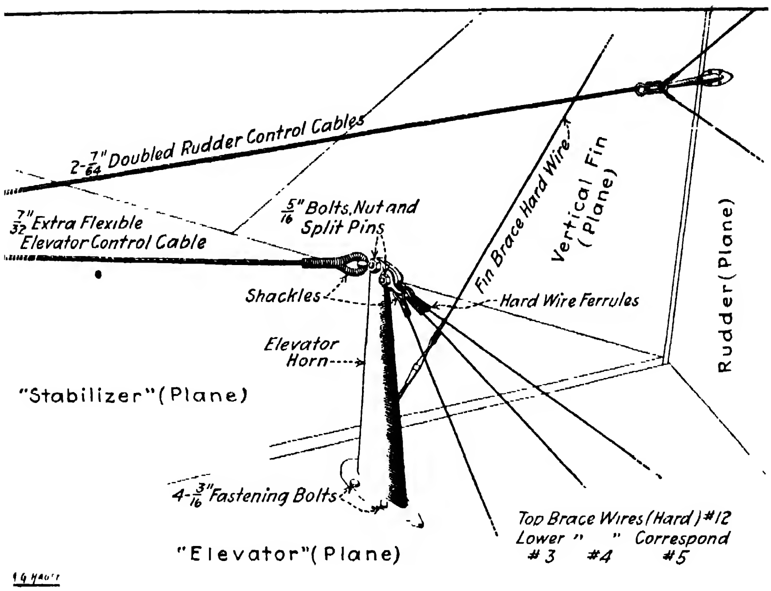


Fig. 300.—Control Pylon of Elevator Showing Wire Control Cable and Hard Wire Bracing.

ing others. The best way, if you have time, is to jack the machine up into its "flying position." If you see a slack wire do not jump to the conclusion that it must be tensioned. Perhaps its opposition wire is too tight, in which case slacken it and possibly you will find that will tighten the slack wire. Carefully examine all wires and their connections near the propeller, and

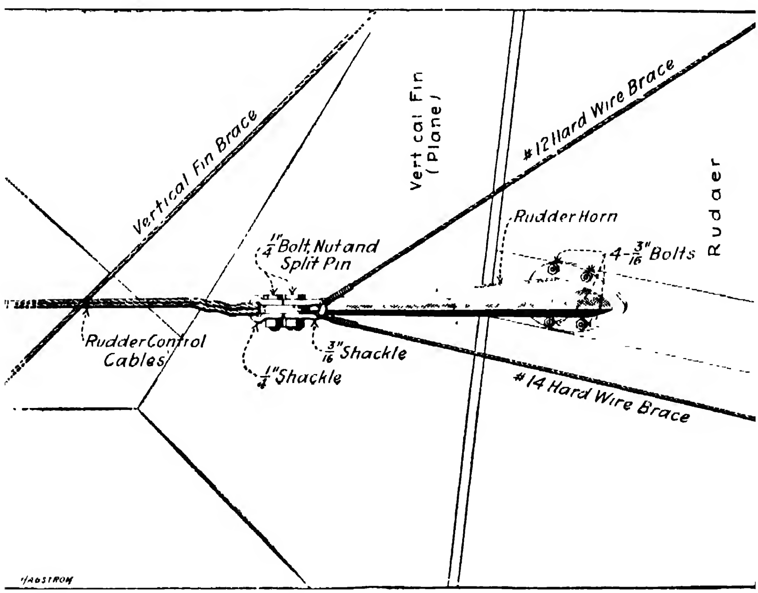


Fig. 301.—Control Horn of Rudder Showing Double Control Cable, Clevises, and Hard Bracing Wires.

be sure that they are snaked round with safety wire, so that the latter may keep them out of the way of the propeller if they come adrift.

The wing skids at the end of each wing on a machine of considerable spread should be looked at to make sure that these are properly secured and not cracked. The control system parts should be checked over periodically and operated to make sure that all the control surfaces operate as they should. In the Dep. control, the cable passes over a drum having a series of grooves cut into it to form a continuous spiral around which the control wire is wrapped. The drum around which the wire is coiled is not always of large diameter, and if wire of exceptional stiffness is used, or one that is not exactly the proper size, it is apt to fray, due to the sharp turn it is forced to make whenever the control is operated.

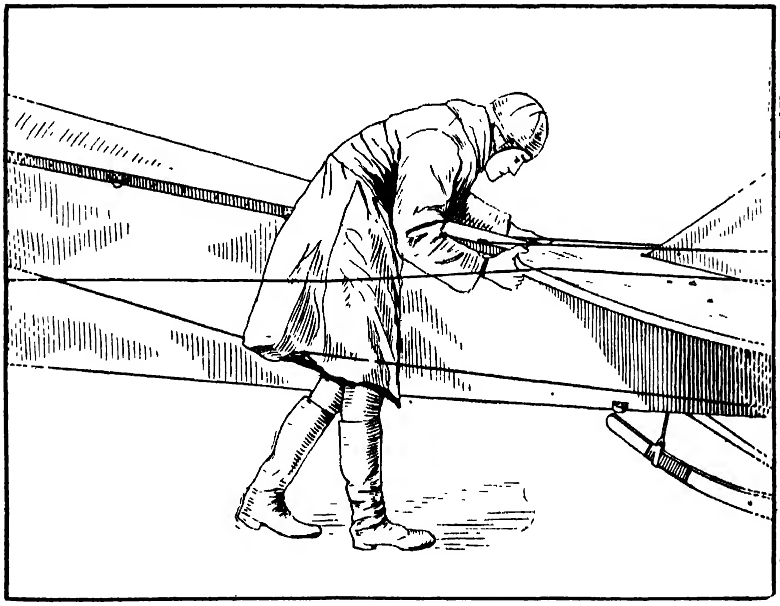


Fig. 302.—Testing Stabilizer Attachment to Fuselage.

If the machine is provided with a stick control, special attention should be given to the universal joints which make it possible to move the stick forward and the control bar sideways at the same time. Naturally, every one of the multiplicity of connections at the control horns must be examined in connection with checking over the control system. Points that are apt to be neglected, such as where the wire runs inside the fuselage, are those which really demand inspection oftenest. By checking over the points enumerated carefully to ascertain if the machine is in proper flying condition before it leaves the ground, all danger of accident due to structural failure when in the air is minimized.

Cleanliness.—The fabric must be kept clean and free from oil, as that will rot it. To take out dirt or oily patches try acetone. If that will not do the job try gasoline, but use it sparingly or otherwise it will take off an unnecessary amount of dope. If that will not remove it, then hot water

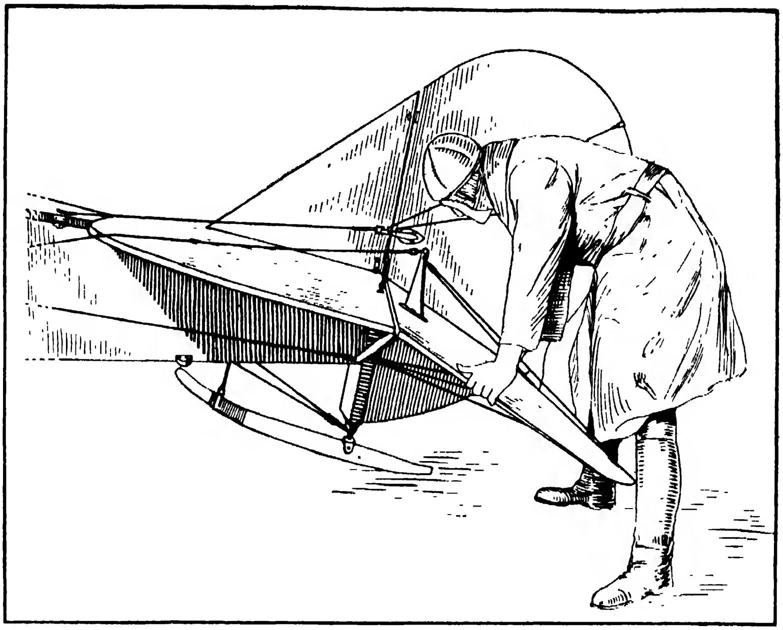


Fig. 303.—Testing Elevators and Attachment to Stabilizer.

and soap will do so, but, in that case, be sure to use soap having but little alkali in it as otherwise it will badly affect the fabric. Use the water sparingly, as otherwise it may get inside the planes and rust the internal bracing wires, or cause some of the members of the wooden framework to swell. The wheels of the undercarriage have a way of throwing up a great deal

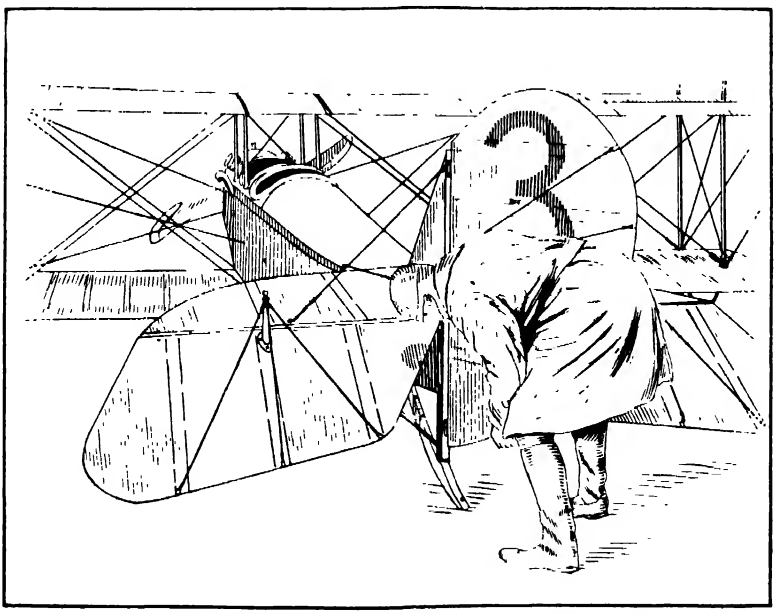


Fig. 304.—Testing Rudder Post and Landing Gear.

of mud on to the lower plane. This should be taken off at once. Do not allow it to dry and do not try to scrape it off when dry. If dry then it must be moistened first as otherwise the fabric will be spoiled. In some airplanes where landings are frequent, as used in schools, mudguards are often fitted over the wheels to keep clods from being thrown into the propeller when taxi-ing over muddy ground.

Weekly Airplane Inspection Card.—When the inspection of airplanes is made by an expert flyer, especially if he is to fly the airplane himself, it is reasonable to assume that everything of importance will be very carefully checked over. If the inspection is intrusted to non-flyers or ground mechanics, unless these men are very conscientious and careful, the inspection will not be as thoroughly made as is necessary as many take certain things for granted and give them only a cursory glance. While Chief Engineering Officer at Hazelhurst Field, Mineola, L. I., the writer evolved a card that had to be filled out at weekly inspection and while this card is for a Curtiss J-N-4 biplane, it is apparent that it can be modified to suit the construction of any machine. The various points to be checked were enumerated and every space had to be filled out. Naturally, when the inspector's signature was on file, if any accident resulted from mechanical failure it was not difficult to check over the inspection card describing the inspection immediately preceding and determine if the defective parts had been noticed. This placed a definite responsibility on every inspector. If anything was found that needed attention the plane was taken off the flying line and sent to the shops. The defects enumerated by the inspector were transcribed by a field clerk to a job card so that all defects found by the inspector were sure to receive attention. The material on the face and back of the card, that proved very useful is reproduced herewith.

Causes of Airplane Accidents.—Twenty-two per cent of airplane accidents controlled by the French Aerial Navigation Service are attributable to engine defects, according to Henri Brunat, chief of this department. Probably the percentage should be placed somewhat higher, for a certain number of non-fatal accidents are not reported to the authorities The order of importance of engine defects is as follows: Mechanical breakages, defective water circulation, defective lubrication, poor carburetion, and defective ignition. Valves and valve operating gear, comprising the valve itself, valve springs, rockers and push rods, head the list of mechanical breakages. Piston breakage comes next. Connecting rod and crankshaft breakage is now rare and can generally be attributed to lubrication defects. The most frequent cause of breakdown on old-type engines is the presence of cracks in the water jackets, caused by differences of expansion and contraction or due to corrosion of the very thin metal employed for the purpose.

In 1923, 12.09 per cent of deaths were due to fire while in flight. Safety measures applied in 1924 reduced the percentage to 1.30 for that year. Later the percentage increased until it became 13.23 per cent during the year 1926. Deaths from fire while on the ground were 16.07 per cent in 1923. The following year safety measures reduced them to 11.76 per cent, but in 1925 they increased to 17.27 and to 26.46 for the year 1926. An examination of the fire accidents shows that 28 per cent were caused by blow

WEEKLY AIRPLANE INSPECTION CARD

Date............ 192

Airplane No............... Make. Model.

Engine No. .... Make. Model.

NOTE: This card must be made out by Field Inspectors of every machine under his charge, signed by him, and must be turned over to the Chief Inspector as soon as made out.

Propeller:

Condition of blades...........
Hub assembly (bolts, washers, cotters) ....
Security to shaft.............
Thrust ....

Gasolene System:

Tank ....
Gasolene leads and connections....
Pump ....
Gasolene in tank........ ... .

Water System:

Leakage ....
Radiator full

Engine:

Valves—

Intake clearance...........
Exhaust clearance.........

Spark Plugs—

Clean ....
Gap ....

Carburetor—

Security to manifold........
Bracing . ...
Manifold joints............

Landing Gear:

Wire tension.....................
Wire terminals...................
Strut sockets (nuts, bolts).........
Loose spokes.....................
Axle greased. ... .
Security of wheels to axle..........
Shock absorber rubbers...........
Tire inflation.....................

Oil System:

Leakage ....
Oil ....

Fuselage Nose:

Tension fuselage bracing........
Tension and terminals wing drag bracing ....
Engine Bed and bolts..........

Magneto—

Mounting ....
Distributor board......
Breaker point clearance
Transmission wear.....

Throttle Control—

Pulleys ....
Wiring ....

Wing Joints: (pins, cotters, safety wires)

Lower wing, right .left.
Upper wing, right. .left.

Wing Wire: (tension, terminals, clevis pins, cotters, safety wires)

Flying wires, right wing..................left ....
Landing wires, right wing.................left.
Wires, fittings, turnbuckles, cleaned and greased.

(Over)

(Face of Card)

Wing Fittings: (bolts, nuts, cotters)

Right Wing { upper ....
lower ....

Left Wing { upper ....
lower ....

Ailerons:

Straightness ....
Hinge assembly—(Lubricate with graphite grease).
Security ....
Wear ....
Hinge pins and cotters..........
Control wire connection (horn)....
Frayed control wire (wheel).....
(pulleys and guides)........
Note: Control wires frayed at any point of their length must be replaced at once.
Pulleys ....
Greased ....
Free running...................

Right ailerons { upper ....
lower ....

Left ailerons { upper ....
lower ....

Rudder:

Hinge assembly..................
Security ....
Wear ....
Hinge pins and cotters..........
Control wire connections..........
Horn ....
Footbar ....
Frayed control wire...........
Note: Control wires frayed at any point of their length must be replaced at once.
Pulleys ....
Greased ....
Free running...................

Alignment of Entire Machine.

Struts:

Sockets, bolts, cotters..............
Straightness ....
Right wing ....
Left wing ....

Stabilizer: (bolts, nuts, cotters, braces) ....

Vertical Fin: (bolts, nuts, cotters)....

Elevators:

Hinge assembly..................
Security ....
Wear ....
Hinge pins and cotters..........

Control wire connection { horn ....
post ....

Frayed control wire.............
Note: Control wires frayed at any point of their length must be replaced at once.
Pulleys ....
Greased ....
Free running ....
Right elevator........................
Left elevator.......................

Tail Skid:

Skid ....
Fittings ....
Shock absorber...................

Fuselage Rear Interior:

Wire tensions ....
Longerons ....
Fittings ....
Alignment ....

Controls:

Free and proper operation (lubricate with graphite grease).
Elevator ....
Rudder ....
Aileron ....

Field Inspector.

(Reverse of Card)

backs into the carburetor, thus igniting the gasoline overflowing from the float chamber, escaping from a badly made connection, or having been allowed to accumulate under the engine housing. Connecting rod breakage was responsible for 24 per cent of the fatal fires; 6 per cent were attributed to defective valves or valve operating gear; 4 per cent were classed as due to defective operation of the engine, without any further description; 2 per cent were due to loose ignition wires on rotary engines.

Dry sump lubrication and other means for keeping the lubricating oil at a low temperature, so as to avoid leaks, is one of the measures recommended to diminish fire risks. Gas and oil tanks should be isolated from the engine housing and should not be immediately behind the engine. A fire curtain between the engine and the gas tank is not sufficient; the protection should be continued on the sides of the tank. Instantaneous emptying of the gas tank in case of a fire has been found unsatisfactory. Owing to the air currents, the liquid is thrown over the fuselage and this causes the fire to spread. Dropping the gas tank in case of danger has given better results, statistics showing that in 20 per cent of cases pilots have escaped disaster by this means. Immediate stoppage of the engine is recommended, and to make this possible the plugs should be of a type not liable to preignition. Several serious accidents have shown that the most dangerous position for the passengers is in the forward part of a fuselage extending beyond the wings, and the safest position is in the fuselage back of the center of gravity of the airplane.

Repairs Necessary in Training Planes.—While at Issoudoun, the writer ordered that the repair department keep a careful accounting of the nature of repairs that were necessary and each job was placed in a certain classification. Aviation school work under the pressure of wartime conditions is very exacting and the frequent landings necessary in training pilots is not always sparing of either personnel or material. The month of October, 1918 was one in which all flying time records were broken and most of the fields were operating at 90 per cent efficiency or better, which means that at least that proportion of their airplanes were in the air. Naturally, the mechanical department was hard pressed to keep up with the breakage. There were 1,354 planes that required work on the motor, such as changing carburetors, magnetos, regrinding valves, retiming valves and other operations that did not require dismantling the engine or its removal from the fuselage. Motors were changed in 398 planes, which indicated either a serious breakdown or the completion of sufficient flying time to require overhauling. Gas tanks were changed in 262 planes which indicates that leakage of fuel containers was a matter that required considerable care in inspection to prevent dangerous fires. The frequent landings and take-offs necessitated relining 584 fuselages, and 284 fuselages required work on the landing gear of minor nature, principally replacing or tensioning bracing wires or changing tires. The axles were changed on 239 planes, however and 121 landing gears required new wheels. Shock absorbers certainly suffered as 485 planes were put in the repair shops to have new shock absorbers fitted. New controls were needed on 79 airplanes for the elevators and 1,123 airplanes needed some minor work on the fuselage such as repairing seats, rudder bars, control cables, etc. Broken longerons caused

64 airplanes to visit the shops while broken wings laid up 528 planes. Only 59 airplanes required new propellers to replace broken ones, which shows that this part of an airplane is pretty reliable, especially as most of the broken propellers were the results of crashes. As the Third Aviation Instruction Center was one that trained pursuit or "chasse" pilots for the most part and several of the fields taught "stunt" flying, it is not to be wondered at that the repair shops required several thousand mechanics in order to maintain an adequate supply of planes for flying.

Recovering Airplane Wings.—One of the most frequent repair jobs in connection with fabric covered wings is the patching and replacement of the covering which depreciates in time, even if the plane is not used. In fact, it is desirable to remove the old fabric when it sags or loses its tautness and replace with new as this gives an excellent opportunity to examine the wing structure, checking over the condition of all spars, ribs, caps, compression tubes and internal brace wires and their fittings. Loose wires can be tightened and any splintered ribs or caps should be replaced before new covering is applied.

Fig. 305.—Cutting Fabric to Pattern before Sewing in Machine.

If the fabric is properly tight and appears to be in good condition except for small rips or holes, the covering can be saved by patching. The method of patching is very simple. The space around the hole or rip is cleaned off to remove all oil for a distance of six inches either side of the hole and a coat of acetate dope is spread on the fabric. A patch is prepared of the proper size to cover the clean area, from linen or cotton fabric, the edges being scalloped. This patch is also sized with dope and pressed down in place over the hole, and is ironed or pressed down with a rounded wood block till all excess dope has been squeezed out from under the patch. The edges are firmly pressed down and the whole patch and adjacent surface

is given a coating of dope which is allowed to dry, after which varnish or varnish and pigment may be applied to have the patched surface match the rest of the wing.

If the material is sagging between ribs and there are numerous tears or holes in the covering the only proper repair is to fit an entirely new cover-

Fig. 306.—Making a Bag of Fabric by Sewing Edges of Pieces cut to Pattern Together.

ing. The first step is to cut the fabric out to patterns, which are painted on the cutting table as shown at Fig. 305. The pieces are then stitched together at the edges on a power sewing machine as shown at Fig. 306 to form a bag open at the fuselage end of the wing frame. This bag is then stretched over the frame, as shown at Fig. 307 and is stitched down to the ribs with cord at intervals of about five or six inches. This stitching is shown at Fig. 308 which also shows the process of doping with brush

applied dope though spraying is the best way when the proper equipment is available. After the linen covering is stitched in place, the ribs are covered with strips of tape having serrated edges which are doped in place. The final coats of wing preservative are put on after the first coat is well set. Sometimes, the stitching is supplemented by fine copper tacks nailed into the rib cap-piece through a piece of narrow tape, these tacks being driven in about one to two inches apart. After doping, the wings are slung up to the ceiling in rope and fabric slings to dry thoroughly. Wings and other control surfaces should be placed in suitable racks, endwise, resting on pads placed under the leading edge. Wings should never be laid flat on the ground or the floor because of liability of damaging the fabric covering.

Fig. 307.—Stretching Fabric Bag over Airplane Wing Frame.

Patching Duralumin.—One of the disadvantages of the duralumin structures, when that material is used for boat hulls or floats, advanced by those favoring other constructions, is the difficulty in repairing a hole punched through the material. The resisting power of metal coverings is very high and when used for wings and properly fastened, it is not subject to deterioration as either veneer or fabric surfaces are. A typical hole, punched through a sheet of metal used in a seaplane float and caused by running against a sharp rock or heavy stick is shown at Fig. 309 A. In examining the sheet in the parts near the break, one should be on the lookout for cracks radiating from the hole. It is recommended that all deformed. cracked or dented metal be cut away to leave a large circular opening as shown at Fig. 309 A. Cutting the sheet is easily done with small curved blade tinner's snips or shears and edges should be filed to smooth any burrs that might result from cutting the sheet. A piece of metal similar to that of which the sheet is composed is cut to the same shape as the hole after it is enlarged with an allowance of one-half inch all around to allow for

rivets. After the piece has been cut to shape, the rivet line is marked around the periphery and rivet centers are indicated with a center punch. In the repair job shown, rivets 3/32 inch diameter were used, spaced on 3/8 inch centers. When rivet locations are indicated on the patching piece, it is placed over the hole and rivet holes are drilled through the sheet patch and ruptured sheet simultaneously. A few machine screws are used to hold the patch in place for rivetting. A dolly bar is used on the inside to rivet against, and rivet sets are used to give a neat round head though they may be peened flat with a hammer. As a precaution to prevent ingress of water, the overlapping surfaces are covered with red lead paste.

Temporary patches are made by using two patching pieces, one inside, the other outside so the injured sheet is sandwiched in between the inner

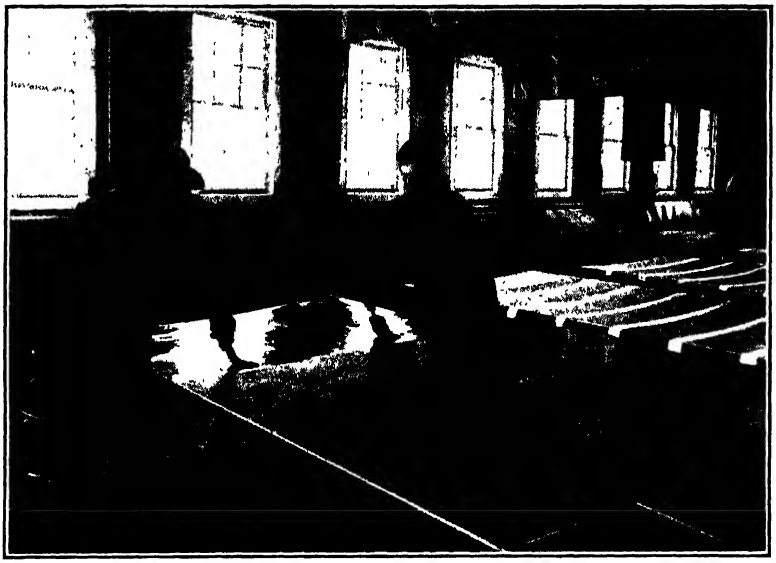


Fig. 308.—After Fabric is Stretched to Ribs with Cord Loops, the Fabric is "Doped" to Make it Air Tight, also to Protect it from the Weather and to Shrink it so the Surfaces between Ribs will be Tight as a Drum Head.

and outer patch sheets. Machine screws, placed about twice as far apart as the rivets are, clamp the three thicknesses of metal together, the heads being on the outside and the nuts on the inside. One of the functions of the reinforcing plate inside the sheet is to prevent the nuts cutting into the metal covering. A repair of this nature, shown at Fig. 309 B is not recommended as a permanent repair as the rivetted patch is much neater and lighter. Rivets should be of the same material as the sheet because if of iron or copper, electrolysis due to difference of potential between dissimilar metals in a saline electrolyte might be set up and corrosion and weakening take place. In rivetting, the line of rivets is about one-quarter of an inch from the edges of the patch, making a very neat repair as shown at Fig. 309 C. The following indicates the proper dimensions for location of rivets and sizes of rivets for different gauges of duralumin suitable for use for repair plates:

Thickness of sheet	Thickness of patch	Diameter of rivet	Rivet spacing
.020	.032	3/32″	3/8″
.025	.040	3/32″	3/8″
.032	.050	1/8″	1/2″
.040	.064	5/32″	5/8″
.050	.064	3/16″	3/4″
.064	.064	3/16″	3/4″

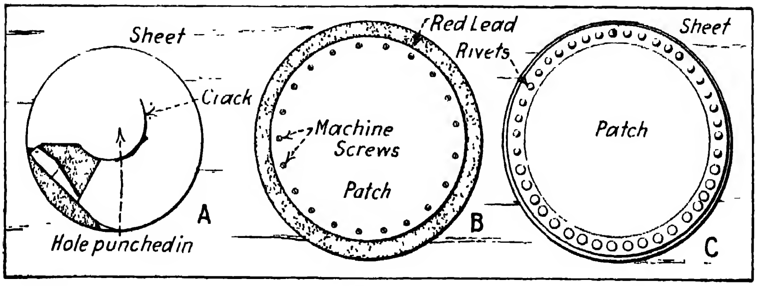


Fig. 309.—Diagrams Showing Method of Patching Duralumin Sheet.

Repairing Tubular Fuselages.—In repairing damaged structural members, the rivets are cut away to permit of removing the bent or broken pieces and an entirely new piece is rivetted in place of a damaged member. All metal airplanes are usually built up of assemblies composed of smaller pieces either rivetted or welded in position. If the piece or minor assembly has been distorted around the break, it is better to remove the entire sub-assembly than to try to straighten out and reline the bent pieces

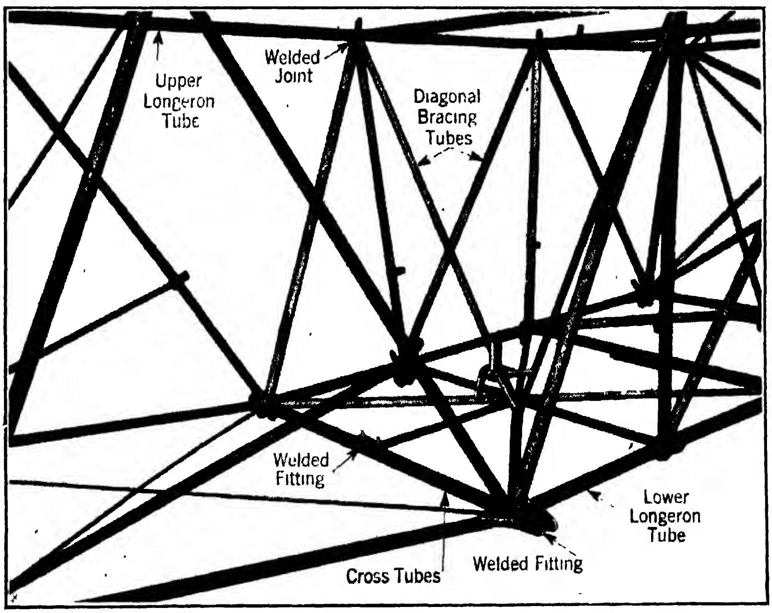


Fig. 310.—Tubular Steel Construction with Flame Welded Joints Used for Fuselage of Pitcairn Orowing Biplane.

around the broken portion of the structure. Broken tubes or cracked members may be repaired by using a reinforcing ferrule inside or outside, welding it in place. A badly distorted tube is best cut entirely out and a new one welded in place. A tubular steel fuselage does not require the bracing wires because the metal tubing used is suitable for resisting both compressive and "stretching" or tensile stress. In the wood and wire fuselage, the wood members are in compression because wood is strongest when the load is acting in that direction that will press the fibers closer together rather than in the direction tending to pull them apart. A typical section of an all tubular steel construction fuselage is shown at Fig. 310, which illustrates a portion of the Pitcairn Orowing, at about its mid-section.

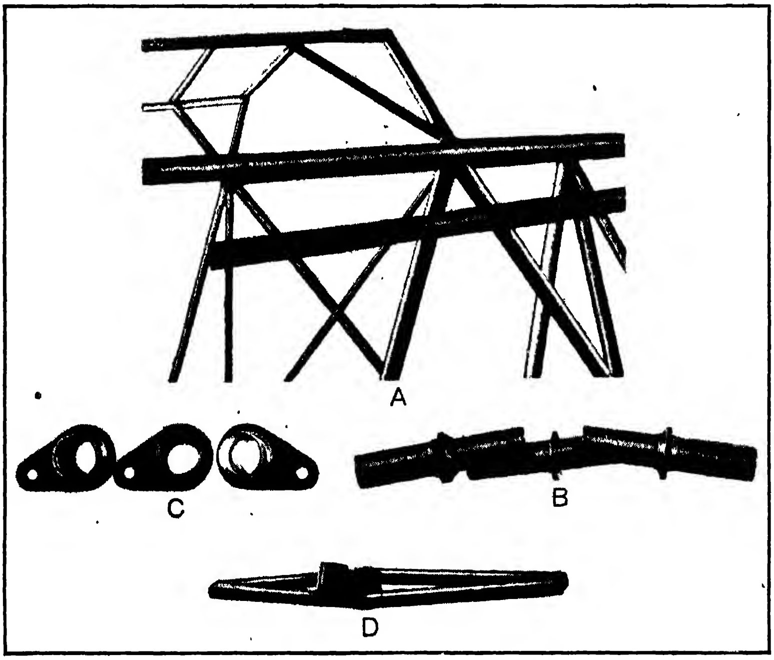


Fig. 311.—Example of Butt-welded Longeron Showing how Tubing Diameter is Reduced from Front to Rear at A, B and C Show Method of Welding Thick Plates to Sleeves, then Welding Sleeve to Tube. D—Cross Brace for Tail Skid Swivel Post Support Showing Removable Bronze Bushing to Take Wear.

The manner in which joints are made by oxy-oxcetylene welding is clearly outlined at Fig. 311. The view at A shows the typical butt weld employed in joining tubular members to the longerons. The longerons are made of tubing of differing sections, smaller diameter tubing being used as the loads decrease. The sizes are such that the next smaller size can slip into the bore of that adjacent to it which is larger after which the smaller tube is maintained in position by welding. The butt joint attachment of the diagonal braces as indicated further reinforces this joint. Whenever a thick plate is to be attached to a tube, the plate is first welded to a sleeve and the sleeve is welded to the tube. This method is illustrated at Fig. 311 B and C. The fuselage cross member supporting the swivel

post of the tail skid is shown at Fig. 311 D. This carries a bronze bushing for a bearing which is easily renewed by pressing it out and replacing with a new one when it becomes worn. The neat welded joints and minimum of burning of the surrounding material is apparent by inspection of the illustrations.

Power Plant Troubles.—There are a number of power plant derangements which give positive indication because of noisy operation. Any knocking or rattling sounds are usually produced by wear in connecting rods or main bearings of the engine, though sometimes a sharp metallic knock, which is very much the same as that produced by a loose bearing, is due to carbon deposits in the cylinder heads, or premature ignition due to advanced spark-time lever. Squeaking sounds invariably indicate dry bearings, and whenever such a sound is heard it should be immediately located and oil applied to the parts thus denoting their dry condition. Whistling or blowing sounds are produced by leaks, either in the engine itself or in the gas manifolds. A sharp whistle denotes the escape of gas under pressure and is usually caused by a defective packing or gasket that seals a portion of the combustion chamber or that is used for a joint as the exhaust manifold. A blowing sound indicates a leaky packing in crankcase. Grinding noises in the motor are usually caused by the timing-gears and will obtain if these gears are dry or if they have become worn. Whenever a loud knocking sound is heard careful inspection should be made to locate the cause of the trouble. Much harm may be done in a few minutes if the engine is run with loose connecting rod or bearings that would be prevented by taking up the wear or looseness between the parts by some means of adjustment.

One who is not thoroughly familiar with engine construction will seldom locate troubles by haphazard experimenting and it is only by a systematic search that the cause can be discovered and the defects eliminated. In this chapter the writer proposes to outline some of the most common power plant troubles and to give sufficient advice to enable those who are not thoroughly informed to locate them by a logical process of elimination. The internal-combustion motor, which is the power plant of all airplanes and airships is composed of a number of distinct groups, which in turn include distinct components. These various appliances are so closely related to each other that defective action of any one may interrupt the operation of the entire power plant. Some of the auxiliary groups are more necessary than others and the power plant will continue to operate for a time even after the failure of some important parts of some of the auxiliary groups. The engine in itself is a complete mechanism, but it is evident that it cannot deliver any power without some means of supplying gas to the cylinders and igniting the compressed gas charge after it has been compressed in the cylinders. From this it is evident that the ignition and carburetion systems are just as essential parts of the power plant as the piston, connecting rod, or cylinder of the motor. The failure of either the carburetor or igniting means to function properly will be immediately shown by faulty action of the power plant.

To insure that the motor will continue to operate it is necessary to keep it from overheating by some form of cooling system and to supply oil

to the moving parts to reduce friction. The cooling and lubrication groups are not as important as carburetion and ignition, as the engine would run for a limited period of time even should the cooling system fail or the oil supply cease. It would only be a few moments, however, before the engine would overheat if the cooling system was at fault, and the parts seize if the lubricating system should fail. Any derangement in the carburetor or ignition mechanism would manifest itself at once because the engine operation would be affected, but a defect in the cooling or oiling system would not be noticed so readily.

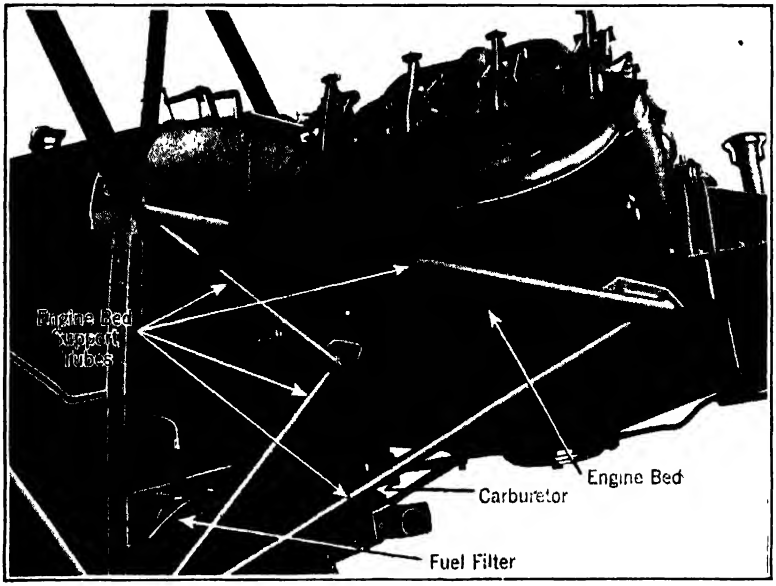


Fig. 312.—Engine Mounting of Pitcairn Orowing. Engine Bearers are Laminated Wood to Absorb Vibration. Note Curtiss OXX5 Engine Installation, Location of Carburetor, Fuel Tank and Fuel Filter. Gravity Fuel Feed is Possible with this Arrangement.

The careful aviator will always inspect the motor mechanism before starting on a trip of any consequence, and if inspection is carefully carried out and loose parts tightened it is seldom that irregular operation will be found due to actual breakage of any of the components of the mechanism. Deterioration due to natural causes matures slowly, and sufficient warning is always given when parts begin to wear so satisfactory repairs may be promptly made before serious derangement or failure is manifested. After a certain amount of flying time, the engine is removed for repairs and the plane is provided with a new power plant. Top overhauls, which mean valve grinding, carbon removal, valve operating gear adjustment and spark plug inspection or renewal are needed periodically, and much more often than a complete overhauling. The simple installation of the Curtiss OX5 engine in the Pitcairn Orowing is shown at Fig. 312. While the fuselage is of steel tubing, as previously described, the engine bed pieces are laminated wood to insulate the fuselage from vibration. The photograph shows how easily all parts of the power plant are reached with the cowling removed.

Trying Out Ignition System.—If a battery is employed to supply current the first step is to take the spark plugs out of the cylinders and test the system by turning over the engine by hand. If there is no spark in any of the plugs, this may be considered a positive indication that there is a broken main current lead from the battery, a defective ground connection, a loose battery terminal, or a broken connector. If none of these conditions are present, it is safe to say that the battery is no longer capable of delivering current. While magneto ignition is generally used on airplane engines, there is apt to be some development of battery ignition, especially on engines equipped with electric self-starters which are now being experimented with. The spark plugs may be short circuited by cracked insulation or carbon and oil deposits around the electrode. The secondary wires may be broken or have defective insulation which permits the current to ground to some metal part of the fuselage or motor. The electrodes of the spark plug may be too far apart to permit a spark to overcome the resistance of the compressed gas, even if a spark jumps the air space, when the plug is laid on the cylinder.

If magnetos are fitted, as is usually the case at present and a spark is obtained between the points of the plug and that device or the wire leading to it from the magneto is in proper condition, the trouble is probably caused by the magneto being out of time. This may result if the driving gear is loose on the armature shaft or crankshaft, and is a rare occurrence. If no spark is produced at the plugs the secondary wire may be broken, the ground wire may make contact with some metallic portion of the chassis before it reaches the switch, the carbon collecting brushes may be broken or not making contact, the contact points of the make-and-break device may be out of adjustment, the wiring may be attached to wrong terminals, the distributor filled with metallic particles, carbon, dust or oil accumulations, the distributor contacts may not be making proper connection because of wear and there may be a more serious derangement, such as a burned out secondary winding or a punctured condenser.

If the motor runs intermittently, i.e., starts and runs only a few revolutions, aside from the conditions previously outlined, defective operation may be due to seizing between parts because of insufficient oil or deficient cooling, too much oil in the crankcase which fouls the cylinder after the crankshaft has revolved a few turns, and derangements in the ignition or carburetion systems that may be easily remedied. There are a number of defective conditions which may exist in the ignition group, that will result in "skipping" or irregular operation and the following points should be considered first: weak source of current due to discharged storage batteries; weak magnets in magneto, or defective contacts at magneto; dirt in magneto distributor or poor contact at collecting brushes. Dirty or cracked insulator at spark plug will cause short circuit and can only be detected by careful examination. The following points should also be checked over when the plug is inspected: Excessive space between electrodes, points too close together, loose central electrodes, or loose point on plug body, soot or oil particles between electrodes, or on the surface of the insulator, cracked insulator, oil or water on outside of insulator. Short circuits in the condenser or internal wiring of induction coils or magnetos, which are

fortunately not common, can seldom be remedied except at the factory where these devices were made. If an engine stops suddenly and the defect is in the ignition system the trouble is usually never more serious than a broken or loose wire. This may be easily located by inspecting the wiring at the terminals. Irregular operation or misfiring is harder to locate because the trouble can only be found after the many possible defective conditions have been checked over, one by one.

Common Defects in Fuel Systems.—Defective carburetion often causes misfiring or irregular operation. The common derangement of the components of the fuel system that occur often enough to warrant suspicion and the best methods for their location follows: First, disconnect the feed pipe from the carburetor and see if the gasoline flows freely from the tank.

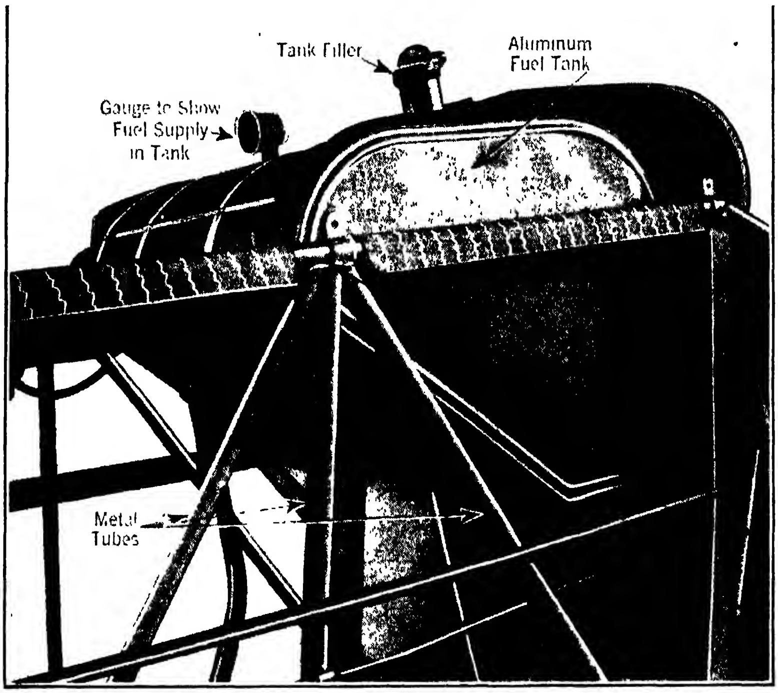


Fig. 313.—Mounting of Aluminum Fuel Tank in Pitcairn Orowing Airplane. Tank may be Removed by Releasing Nut and Straps and without Disturbing Top Cowling.

If the stream coming out of the pipe is not the full size of the orifice it is an indication that the pipe is clogged with dirt or that there is an accumulation of rust, scale, or lint in the strainer screens of the filter. A typical gravity feed installation is shown at Fig. 312, as well as the location of the fuel tank, filter and Duplex Zenith Carburetor. It is also possible that the fuel shut-off valve may be wholly or partly closed. If the gasoline flows by gravity the liquid may be airbound in the tank, while if a pressure feed system is utilized the tank may leak so that it does not retain pressure; the check valve retaining the pressure may be defective or the pipe conveying the air or gas under pressure to the tank may be clogged.

If the gasoline flows from the pipe in a steady stream, showing that there is no obstruction in the line, the carburetor demands examination. There may be dirt or water in the float chamber, which will constrict the passage between the float chamber and the spray nozzle, or a particle of foreign matter may have entered the nozzle and stopped up the fine holes therein. The float may bind on its guide, the needle valve regulating the gasoline-inlet opening in bowl may stick to its seat. Any of the conditions mentioned would cut down the gasoline supply and the engine would not receive sufficient quantities of gas. Air may leak in through the manifold, due to a porous casting, or leaky joints in a built up form and dilute the mixture. Water or sediment in the gasoline will cause misfiring because the fuel feed varies when the water or dirt constricts the standpipe bore.

It is possible that the carburetor may be out of adjustment. If clouds of black smoke are emitted at the exhaust pipe it is positive indication that too much gasoline is being supplied the mixture and the supply should be cut down by making sure that the fuel level is at the proper height, or that the proper nozzle is used in those forms almost universally used in airplanes where the spray nozzle has no means of adjustment. If the mixture contains too much air there will be a pronounced popping back in the carburetor. When a carburetor is properly adjusted and the mixture delivered the cylinder burns properly, the exhaust gas will be clean and free from the objectionable odor present when gasoline is burned in excess. The character of combustion may be judged by the color of the flame which issues from it when the engine is running with an open throttle after nightfall. If the flame is red, it indicates too much gasoline. If yellowish, it shows an excess of air, while a properly proportioned mixture will be evidenced by a pronounced blue flame, such as given by a gas-stove burner.

Leakage of gasoline, either at tank seams or pipe line joints must be corrected immediately. The aluminum tank mounting on the Pitcairn Orowing plane is shown at Fig. 313 and the installation is such that the tank may be removed by releasing retention nuts and straps without removing cowling for testing or repairing.

Zenith Carburetor Adjustment.—The Duplex Model Zenith carburetor used upon most of the six-, eight- and twelve-cylinder airplane engines consists of a single float chamber, and a single air intake, joined to two or three separate and distinct spray nozzles, venturi and idling adjustments. The mounting is such that fuel may be fed by gravity in some airplanes as shown at Fig. 312 where it is carried well below the engine. The location of the fuel filter is also clearly shown. It is to be noted, that as the carburetor barrels are arranged side by side, both valves are mounted on the same shaft, and work in unison through a single operating lever. It is not necessary to alter their position. In order to make the engine idle well, it is essential that the ignition, especially the spark plugs, should be in good condition. The gaskets between carburetor and manifold, and between manifold and cylinders should be absolutely air-tight. The adjustment for low speed on the carburetor is made by turning in or out the two knurled screws, placed one on each side of the float chamber. After starting the engine and allowing it to become thoroughly warmed, one side

of the carburetor should be adjusted so that the three cylinders it affects fire properly at low speed. The other side should be adjusted in the same manner until all six cylinders fire perfectly at low speed. As the adjustment is changed on the knurled screw a difference in the idling of the engine should be noticed. If the engine begins to run evenly or speeds up it shows that the mixture becomes right in its proportion. In some radial air-cooled engines having nine cylinders, a triple throat device may be used, each separate throat or carburetor mixing chamber serving three of the nine cylinders.

Be sure the butterfly throttle is closed as far as possible by screwing out the stop screw which regulates the closed position for idling. Care should be taken to have the butterfly held firmly against this stop screw at all times while idling engine. If three cylinders seem to run irregularly after changing the position of the butterfly, still another adjustment may have to be made with the knurled screw. Unscrewing this makes the mixture leaner. Screwing in closes off some of the air supply to the idling jet, making it richer. After one side has been made to idle satisfactorily repeat the same procedure with the opposite three cylinders. In other words, each side should be idled independently to about the same speed.

Remember that the main jet and compensating jet have no appreciable effect on the idling of the engine. The idling mixture is drawn directly through the opening determined by the knurled screw and enters the carburetor barrel through the small hole at the edge of each butterfly. This is called the priming hole and is only effective during idling. Beyond that point the suction is transferred to the main jet and compensator, which controls the power of the engine beyond the idling position of the throttle.

Defects in Oiling Systems.—While troubles existing in the ignition or carburetion groups are usually denoted by imperfect operation of the motor, such as lost power, and misfiring, derangements of the lubrication or cooling systems are usually evident by overheating, diminution in engine capacity, or noisy operation. Overheating may be caused by poor carburetion as much as by deficient cooling or insufficient oiling. When the oiling group is not functioning as it should the friction between the motor parts produces heat. If the cooling system is in proper condition, as will be evidenced by the condition of the water in the radiator, and the carburetion groups appears to be in good condition, the overheating is probably caused by some defect in the oiling system.

The conditions that most commonly result in poor lubrication are: Insufficient oil in the engine crankcase sump or in oil tank in dry sump systems, broken or clogged oil pipes, screen at filter filled with lint or dirt, broken oil pump, or defective oil pump drive. The supply of oil may be reduced by a defective inlet or discharge check valve if a plunger pump is used or worn pumps. A clogged oil passage or pipe leading to an important bearing point will cause trouble because the oil cannot get between the working surfaces. It is well to remember that much of the trouble caused by defective oiling may be prevented by using only the best grades of lubricant, and even if all parts of the oil system are working properly, oils of poor quality will cause friction and overheating.

Water-Cooling System Troubles.—Cooling systems are very simple and

are not liable to give trouble if in good repair if the radiator is kept full of clean water and the circulation is not impeded. When overheating is due to defective cooling the most common troubles are those that impede water circulation. If the radiator is clogged or the piping of water jackets filled with rust or sediment the speed of water circulation will be slow, which will also be the case if the water pump or its driving means fail. Any scale or sediment in the water jackets or in the piping or radiator passages will reduce the heat conductivity of the metal exposed to the air, and the water will not be cooled as quickly as though the scale was not present.

The rubber hose often used in making the flexible connections demanded between the radiator and water manifolds of the engine may deteriorate inside and particles of rubber hang down that will reduce the area of the passage. The grease from the grease cups mounted on the pumpshaft bearing to lubricate that member often finds its way into the water system and rots the inner walls of the rubber hose, this resulting in strips of the partly decomposed rubber lining hanging down and restricting the passage. Sometimes a hose connection will buckle and the passage through it will be greatly restricted. The greatest enemy of a water-cooling system is vibration and most of the troubles in flight result from cracked tubes or leaky water jackets and radiator cores. In event of loss of water, the engine will soon heat up because a cooling system for airplanes is very closely figured to save weight and everything must be working properly to insure good cooling. Sometimes a relatively small leak will cause overheating because after a certain amount of water is lost, the remaining liquid will get abnormally hot and steam away. For this reason, even the slightest leaks should be repaired as soon as it is disclosed by inspection.

Radial Air-Cooled Engines.—This table of the commonest troubles and their causes is submitted to the service men with the object of reducing wasted time and increasing the reliability of the Whirlwind engine by the makers of that very reliable and efficient power plant.

If Engine Fails to Start it may be due to any one of the following causes:

1. *Lack of Fuel.* Examine fuel supply, shut off cocks, traps, strainers and hose connections.
2. *Under Priming* or *Over Priming.* See instructions on starting.
3. *Booster Magneto Defective.* Examine and test the starting magneto.
4. *Throttle Opening Incorrect.* The throttle should be approximately one-eighth open while starting.
5. *Defective Ignition Wire.* Examine ignition wiring for wear, breaks and incorrect connections.
6. *Dirty Spark Plugs.* Check spark plugs for proper functioning. Clean and set gaps (B.G., .015 inch; A.C., .020 inch to .025 inch).
7. *Incorrect Valve Tappet Clearance.* Check the valve tappet clearance.
8. *Incorrect Timing.* Check valve and ignition timing.
9. *Water in Carburetor.* Remove a plug from the bottom of the carburetor and drain out gas and water.
10. *Cold Oil.* With the ignition switches off, turn the engine over by

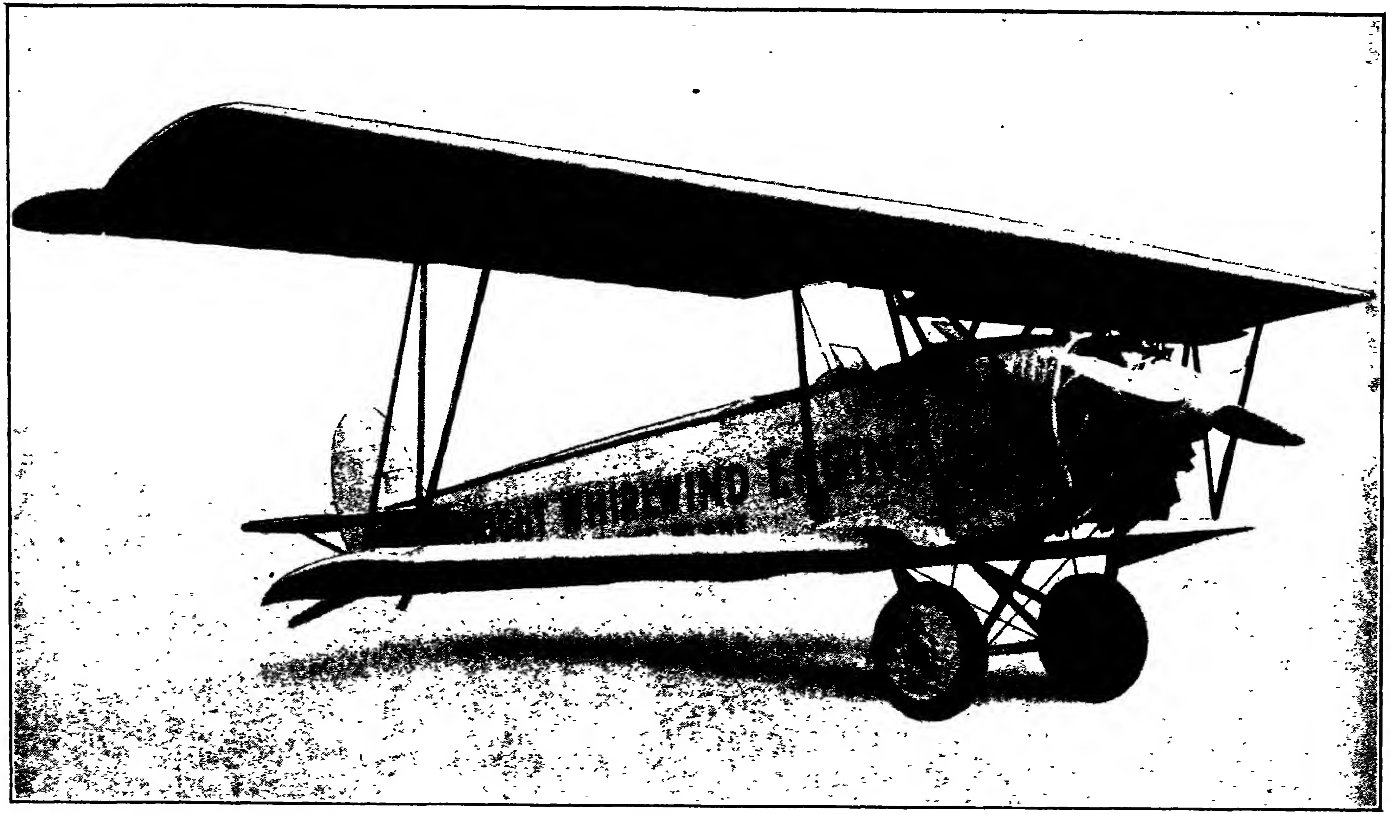


Fig. 314.—Fokker S 3 Training Plane Uses Radial Air-Cooled Whirlwind Engine. Metal is Used for Fuselage Construction, Interplan and Landing Gear Struts. Note Absence of Bracing Wires. Plane Shown is Used as an Engine Service Plane by the Engin Manufacturers.

hand. If it is very stiff it will be necessary to heat the oil before starting.

11. *Magneto Breaker Points.* See that the magneto breaker points are clean and have the proper gap (.012 inch). Test spark delivered by magneto.
12. *Miscellaneous.* Examine the engine carefully for unusual conditions, turning over slowly by hand.

Low Oil Pressure or none at all may be caused by

1. *Lack of Priming.* Disconnect the oil suction line and fill the pump with oil. Turn engine over by hand until oil is sucked into pump. Check oil supply.
2. *Leak in Suction Lines.* Examine the oil suction lines for air leaks.
3. *Dirt in Oil Screen.* Remove and clean the oil strainer.
4. *Oil Pressure Relief Valve.* Examine the oil pressure relief valve and spring for proper seating or breakage.
5. *Gun Synchronizers or Starter Dog Removed.* The gun synchronizers are on the main oil line and if removed should be replaced with dummy parts (No. 18828). The same is true of the starter dog which should be replaced with part No. 19980 and the retaining screw (J-5 No. 19712 or J-4B No. 17177).
6. *Crankshaft Plug Out.* Remove a cylinder and examine the crankshaft plugs.
7. *Excessive Bearing Clearance.* A bearing may be worn enough to cut down the pressure in which case an overhaul will be necessary.

Crankcase Filling with Oil is usually caused by lack of priming in the discharge pump. Disconnect the main discharge line from the engine and put on a two foot length of garden hose. Feed oil into this hose while turning the engine backwards until a quart or so has been sucked in. Check oil pumps, strainers and lines for failures or stoppages.

Engine Runs Unevenly and does not come up to power. The full throttle speed of the engine will vary 75 to 100 r.p.m. under different atmospheric conditions. It will also vary considerably with the condition of the propeller. Therefore the engine should not be considered low on power unless the drop in speed is excessive under similar conditions.

Low power and uneven running may be traced to any of the following causes:

1. *Rich or Lean Mixture.* Make sure the mixture control lever is in the best position.
2. *Leaks in Induction System.* Examine the intake pipes for cracks and for leaks at the cylinder and crankcase connections. Examine the carburetor and manifold flanges for tightness. Examine pipe plugs in cylinder inlet ports to see that they are all tight.
3. *Spark Plugs.* See that all the spark plugs are clean and that they have the proper clearance.
4. *Valve and Valve Gear Trouble.* Check valve tappet clearance, springs, washers, rocker arms, and push rods. Be sure the push rods on

J-4 series engines have not been interchanged. The cam followers nearer the propeller operate the exhaust valves. See that the valves are not sticking.

5. *Poor Fuel.* Make sure the fuel being used is a good grade of domestic aviation gasoline and that it flows freely to the carburetor.
6. *Magneto Breaker Points.* See that the magneto breaker points are clean and have the proper gap (.012 inch). Check operation of magnetos.
7. *Engine Overheating.* This may be caused by items 1, 2, 3, and 5 above. It is easily recognized by the fact that the engine will run at normal speed just after idling and will then slowly fall off. Continued running of an engine exhibiting this symptom is liable to cause considerable damage so an investigation of the cause should be started immediately. Other causes are improper cowling, excessive air temperature, thin oil, and insufficient oil-cooling.

Excessive Oil Temperature may be caused by

1. Insufficient oil-cooling.
2. Insufficient oil supply. There should be at least two gallons of oil in the system.
3. Low grade oil. See that the oil being used is up to specification.
4. Suction pump failing to scavenge oil properly from crankcase. Examine all oil lines for leaks.
5. Overheated Bearing. If the trouble is not found after an investigation of 1, 2 and 3, a bearing may be overheating, in which case a disassembly will be necessary.

Carburetor Leaking.—Because of the fire hazard the engine should not be run if the carburetor leaks gasoline excessively. This may be caused by

1. Leaky float.
2. Stuck float.
3. Poor seating of needle valve.
4. Wear of float fulcrum pin.

In any case the carburetor should be removed and checked over. If the float has been leaking the gasoline should be removed, the hole soldered, and the float immersed in hot water to test for tightness. The needle valve seat should be removed, the valve lapped in with fine compound and the assembly tested for tightness and float level.

QUESTIONS FOR REVIEW

1. Name important things to look for when inspecting propeller.
2. What parts of the power plant require inspection before every flight?
3. Why should an engine be run for a time before the airplane leaves the ground?
4. Describe points on landing gear that must be looked over.
5. Give inspection routine for water-cooled engine.
6. Give inspection routine for air-cooled engine.
7. Outline instructions for starting airplane engines.
8. What points on the wings need inspection?
9. What defects would you look for in the fuselage and controls?
10. Outline steps in recovering wood and fabric airplane wings.

CHAPTER XV

DETAILS OF MODERN AIRSHIPS AND AIRPLANES

Advantages of Rigid Type Airships—Airship Frame Construction—Large Airships Projected—Army Non-rigid Dirigibles—Requirements of Airships for Civilian Flying—Light, Low Powered Airplanes—The Short "Satellite"—The Westland Wood Pigeon—The Westland Widgeon—Ryan M1 Monoplane—K. R. A. Light Monoplane—Pander (Dutch) Light Plane—Medium Weight Planes—Pitcairn Orowing—Buhl-Verville CW3—Fokker Universal Monoplane—Wright-Bellanca Monoplane—Curtiss Carrier Pigeon—Curtiss Falcon Observation Plane—Multi-Motored Airplanes—Diesel Engines Proposed—Heinkel Twin-Motor Biplane—Caproni CA73 Bomber—The C. P. A. 1 Two-Motor Bomber—Remington-Burnelli Airliner—Fokker Tri-motor F VII—Fokker Power Plant Installation—General Fokker Features—Bleriot Four Engine Airliner.

Advantages of Rigid Type Airship.—Before describing typical lighter-than-air craft or airships that have received actual commercial as well as military usage, it may be well to briefly review some of the advantages of the rigid type, which is the one that lends itself most easily to large structures and which is also the safest of the three types we have previously reviewed in Chapter II which is devoted to a consideration of the elementary principles underlying airship construction and application. Rigid airships have made longer single flights than other types and have flown more hours and miles without refueling than any other form. The rigid airship is said to be the fastest large vehicle of transportation that engineering ability of man has yet evolved. The Navy Airship Los Angeles, shown near the mooring mast at Lakehurst, N. J. to which it may be anchored is depicted at Fig. 315. A design of the new 6,500,000 cubic foot capacity ship recently authorized by Congress is shown at Fig. 316 flying over a battleship at an elevation of about 1,500 feet. The rigid airship, owing to its large size and light weight can carry more load than any other type of aircraft. It is independent of topography as oceans and continents are but areas to fly over. Land vehicles must stop when they reach water, water transport must stop when the ship is docked.

Airship Frame Construction.—The rigid airship, because of its bulkhead system, in which the lifting gas is carried in 16 to 20 cells, has a much greater safety factor than the types in which the gas is carried in only one or two containers. In event of damage to one or two cells, the ship can continue its journey and repairs can be made to a leaky gas cell while in flight.

The rigid ship has a complete metal framework. Girders extend from nose to tail, or in nautical parlance, from stem to stern. Ring girders set at intervals brace the longitudinals and are themselves internally reinforced by cross girders and tension wire bracing. The entire framework is enclosed by a network of wiring and the whole is streamlined or faired to minimize air resistance with a fabric covering.

The view of the crew's quarters on the Bodensee, a German air liner at Fig. 317, shows the triangular keel member with the cat-walk by which the crew can travel from one end of the ship to the other and gain access to the different gas bags. The character of the longitudinal duralumin girders and the way they are braced by the ring girders is clearly shown at Fig. 318. This depicts that portion of the hull where one set of fuel tanks are located. The view at Fig. 319 shows the interior with the deflated gas cells hanging from the top-most longitudinal ready for inflation. The outer skin is in place and the large size and extreme lightness of the structure is clearly shown. The passenger cabin of the Deutschland, another rigid dirigible of the Zepellin series is shown at Fig. 320. Wicker chairs are used because of their light weight and the interior structure of the cabin

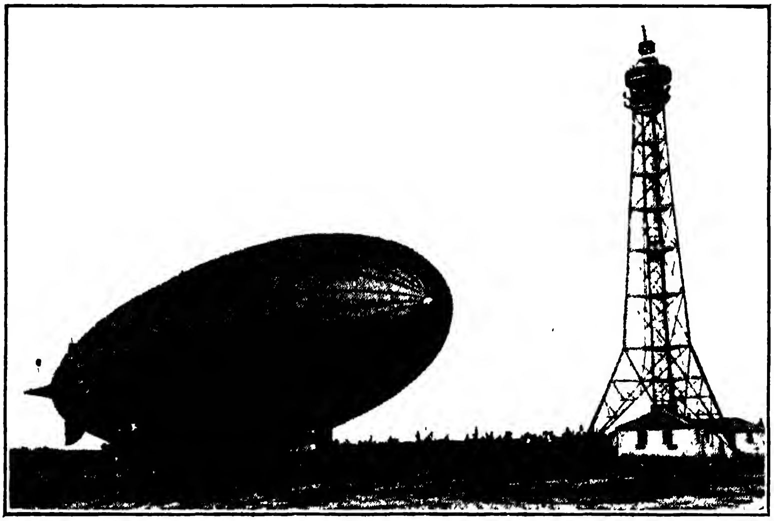


Fig. 315.—The U. S. Navy Rigid Dirigible Los Angeles Held Down by Landing Party Prior to Mooring at Special Mast for that Purpose at Lakehurst, N. J.

can be determined by study of the illustration. The control of a Zepellin type airship is not as simple as that of an airplane and no one man is at the controls. Special controls are provided for the elevators and still another set for the vertical rudders. The elevator control of the L59 with the instruments for altitude navigation is shown at Fig. 321. Control is by a large wheel similar to the steering wheel of a ship. Directional control is by a similar wheel at another part of the control car.

Large Airship Projected.—The largest of the United States Navy airships, the Shenandoah was 600 feet long with a capacity of 2,115,000 cubic feet. The projected airship designed by the engineers of the Goodyear-Zepellin Company, while it has over three times the capacity of the Shenandoah will be only 100 feet longer and will be of such size that it may be housed in the Lakehurst hangar. The illustration at Fig. 322 shows how the new ships authorized by congress will compare with the Shenandoah. The control car will be built into the hull and streamlined. Engines of 4,800 horsepower, giving a speed of 90 miles per hour with fuel for from

5,000 to 8,000 miles will drive the ship. The air screws will be fitted in tilting mountings, which will turn in a 90 degree arc to help force the ship upward or downward as desired and greatly aid in controlling the huge vessel.

It will embody the proved structural advantages of some 135 ships built in the past.

(a) Multiple gas cells which function like bulk-heading on a steamship, so that if one or more cells fail the ship will still remain aloft: (b) The triple cover system, one cover to hold the lifting gas, one consisting of the shape-forming duralumin frame-work, and an outer cover to shed rain and snow, to reflect rather than to absorb heat, and to present a fair surface; (c) invulnerability against lightning; (d) accessibility to inspection and repair.

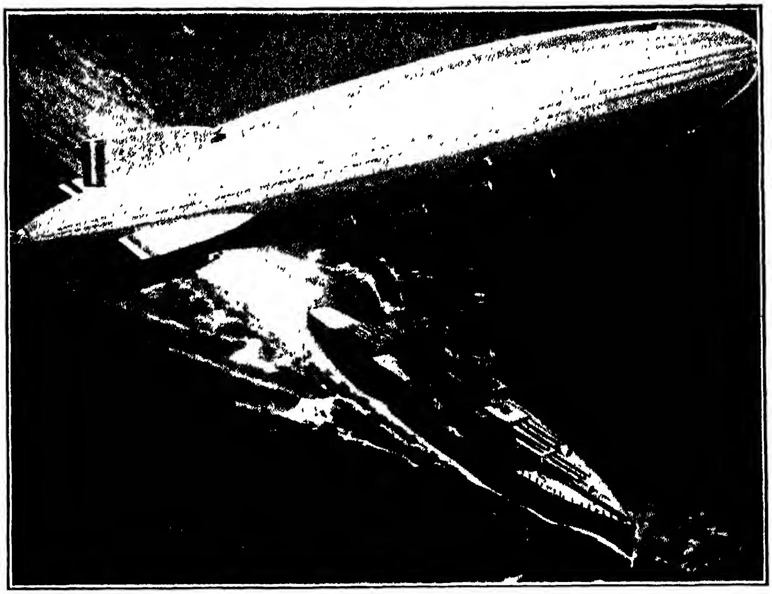


Fig. 316.—New Airship that will have over Three Times the Gas Capacity of the Los Angeles, as it will Look Flying over Battleship New Hampshire.

It will however present certain new features as well of far reaching importance: (a) A double or triple keel giving added longitudinal strength comparable to the breaking strength of one length of metal, as against two or three bolted together; (b) a new type of ring girder each internally braced and structurally self sufficient, which (c) will permit the control car and even the power cars to be built within the hull; (d) even fuller accessibility to continuous inspection and permitting repairs to be made even in flight; (e) the use of new fuels to conserve helium and reduce weight.

Army Non-Rigid Dirigibles.—The non-rigid dirigible is the smallest of the three types as the largest now being built in the United States for the Army and Navy service have a gas capacity of about one-tenth that of the Los Angeles. Under ordinary conditions a 230,000 cubic foot non-rigid has a cruising radius of from 500 to 1,000 miles and an air endurance of

from 18 to 24 hours. Such airships are essentially motorized free balloons and the engines are carried in a car attached to the lower side or bottom of the bag. The Pilgrim, a small non-rigid previously described with a gas capacity of 50,000 cubic feet has a speed of 50 miles per hour and is propelled by a Wright "Gale" three-cylinder engine as shown at Fig. 323. This small ship was built to carry four passengers. The gas in non-rigid ships, as in the army TC types, as shown at Fig. 324 is contained in a single bag, but an inner two compartment bag, called the ballonet, is filled with air to keep the main container properly distended because the air pressure can be made to compensate for variations in gas pressure in the bag. These ships have a capacity of about 200,000 cubic feet, are 196 feet

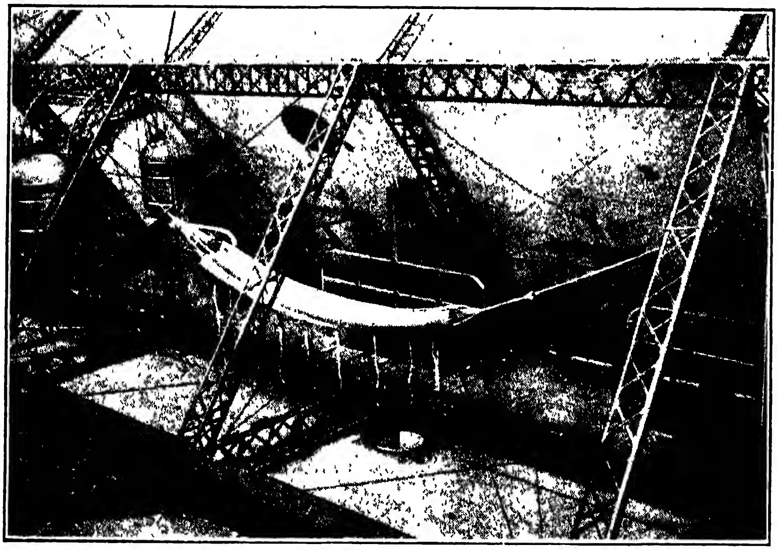


Fig. 317.—Crew's Quarters on Bodensee, a German Zeppelin. Note Construction of Duralumin Girders Built Up of Numerous Small Pieces.

long overall and 47 feet in extreme height. The hull diameter is 33.5 feet. The fineness ratio is 4.4 to 1. The total lift is 11,584 pounds of which the useful lift is about 4,000 pounds. The gross weight per horsepower is 38.6 pounds. Two Wright Type I water-cooled engines of 150 horsepower each were provided on the first ships of this series but these have been replaced on later types with two Wright J1 engines, which are nine-cylinder radial air-cooled types driving tractor propellers 9 feet 10 inches in diameter. It is claimed that the saving of 400 pounds over the water-cooled installation permits an increase of speed from 54 to 60 miles per hour; with an increase in range of 10 per cent.

Requirements of Airplanes for Civilian Flying.—Mr. L. G. Meister, M. S. A. E. of the Buhl Aircraft Company, Marysville, Mich. has discussed some of the features he believes desirable to incorporate in airplanes for civilian flying and as he is a pilot of considerable experience, his comments are worthy of careful consideration. He states:

Fig. 318.—View of the Interior of the Zeppelin Rigid Airship, the Bodensee, Showing how Ring Frames and Longitudinal Girders Form Light Framework of Hull.

"Folding wings are a desirable feature from the viewpoint of easy storage, or of towing from one field to another without dismantling. When folded in place and left in the open, the airplane does not require staking down, and it can be stored in the average barn.

Fig. 319.—Interior View of the Framework of the Zeppelin "Bodensee" Showing Deflated Gas Bags of Gold Beater's Skin Hanging from the Top of the Structure.

Ease of maintenance and accessibility require quick, detachable engine-cowling, as well as large inspection plates for fuselage, control and tail skid inspections. When accessibility for inspection is good, maintenance and inspection are not slighted.

Instruments should be readily visible. They should not have too many graduations and should have the main graduations marked with luminous paint as this is imperative for flying through bad weather and darkness.

The choice between round-dial and vertical-dial instruments is a matter of personal preference, with the old pilots favoring the round-dial type because they are familiar with them.

Modern airplanes usually have more than one fuel tank and the standard Air Service three-way fuel valve with geared pump has proved the best because it is positive and eliminates the fire hazard caused by using air pressure in an air-tight fuel tank. Gravity feed tanks for emergency use

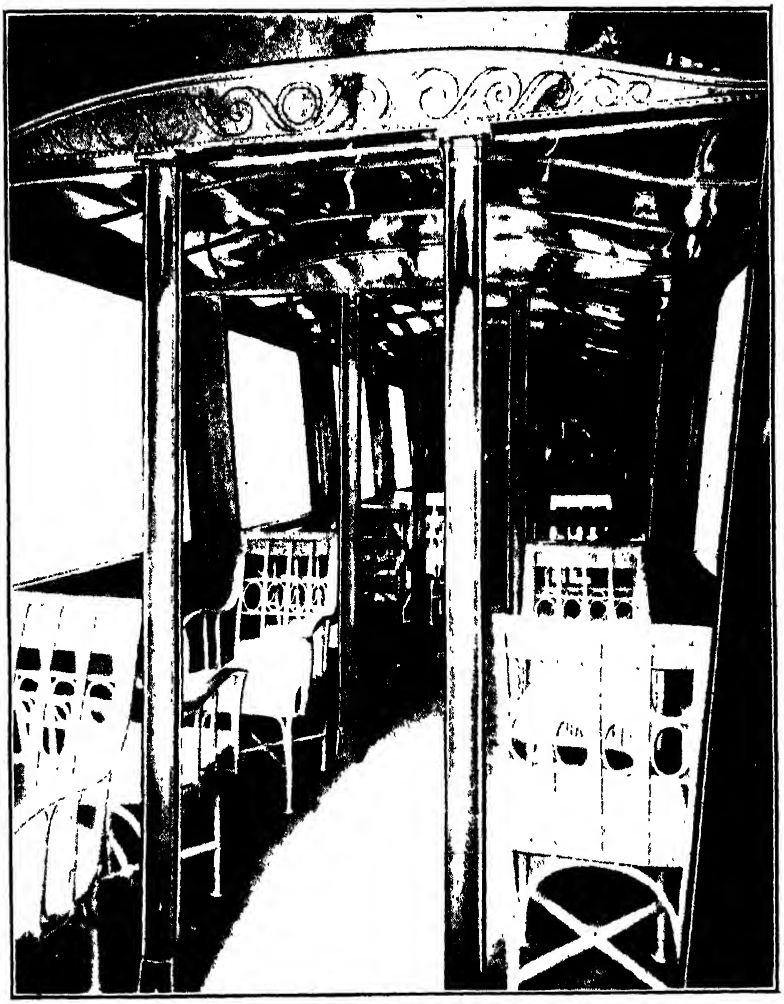


Fig. 320.—Interior View of the Passenger Cabin of the Deutschland Showing Comfortable but Light Wicker Arm Chairs and Large Windows for Observation Purposes.

easily can be located in the upper wing panels, and this system is practically standard.

More attention should be and will be paid to easy entrance to and egress from cabins and cockpits, and more study will be given to muffling the engine exhaust. The whirling chamber type of exhaust manifold has given

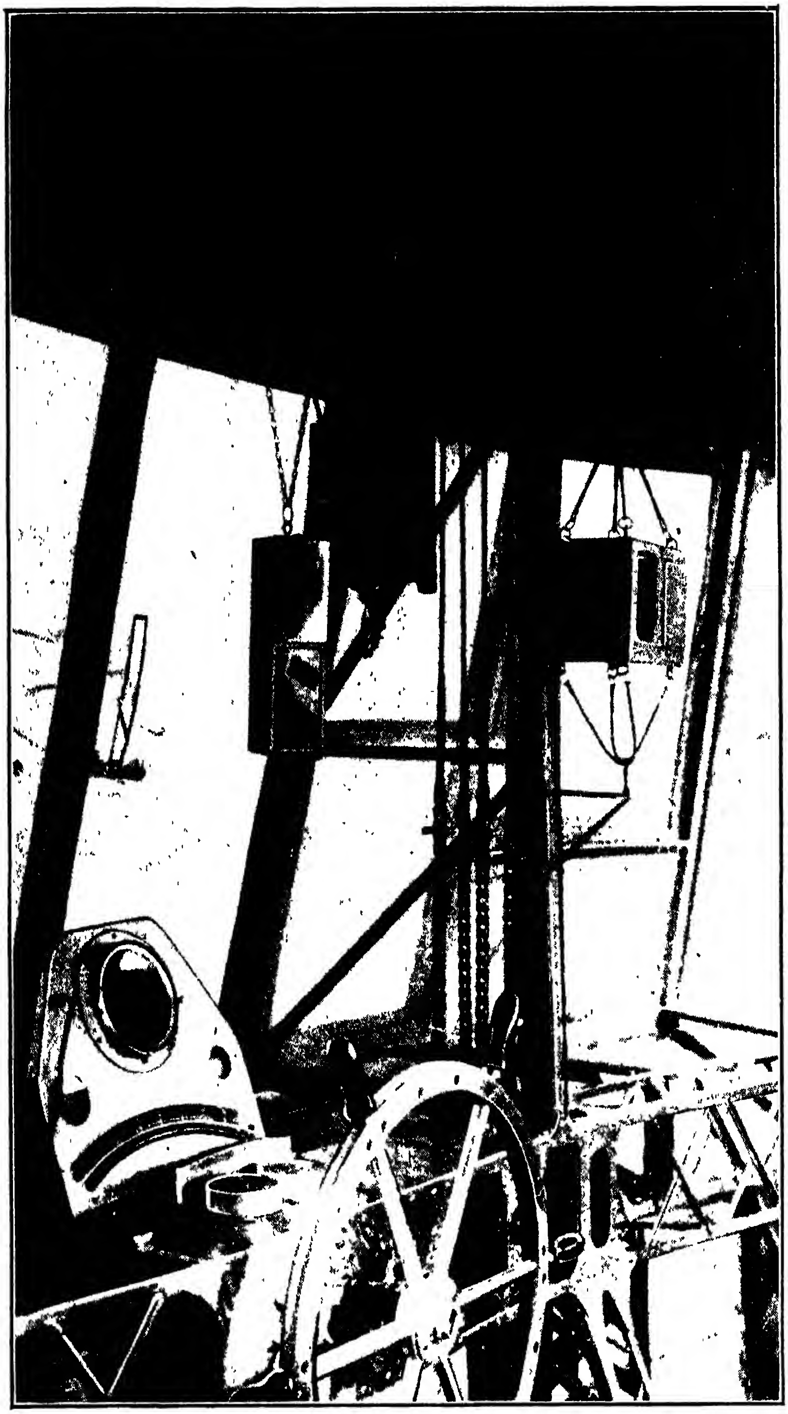


Fig. 321.—Part of the Control Car of the "L 59" Showing Wheel for Elevator Control and Instruments for Alti.ude Indication for Guidance of Helmsman. A Similar Installation on the Other Side of Cabin Controls Vertical Rudder and Horizontal Movements.

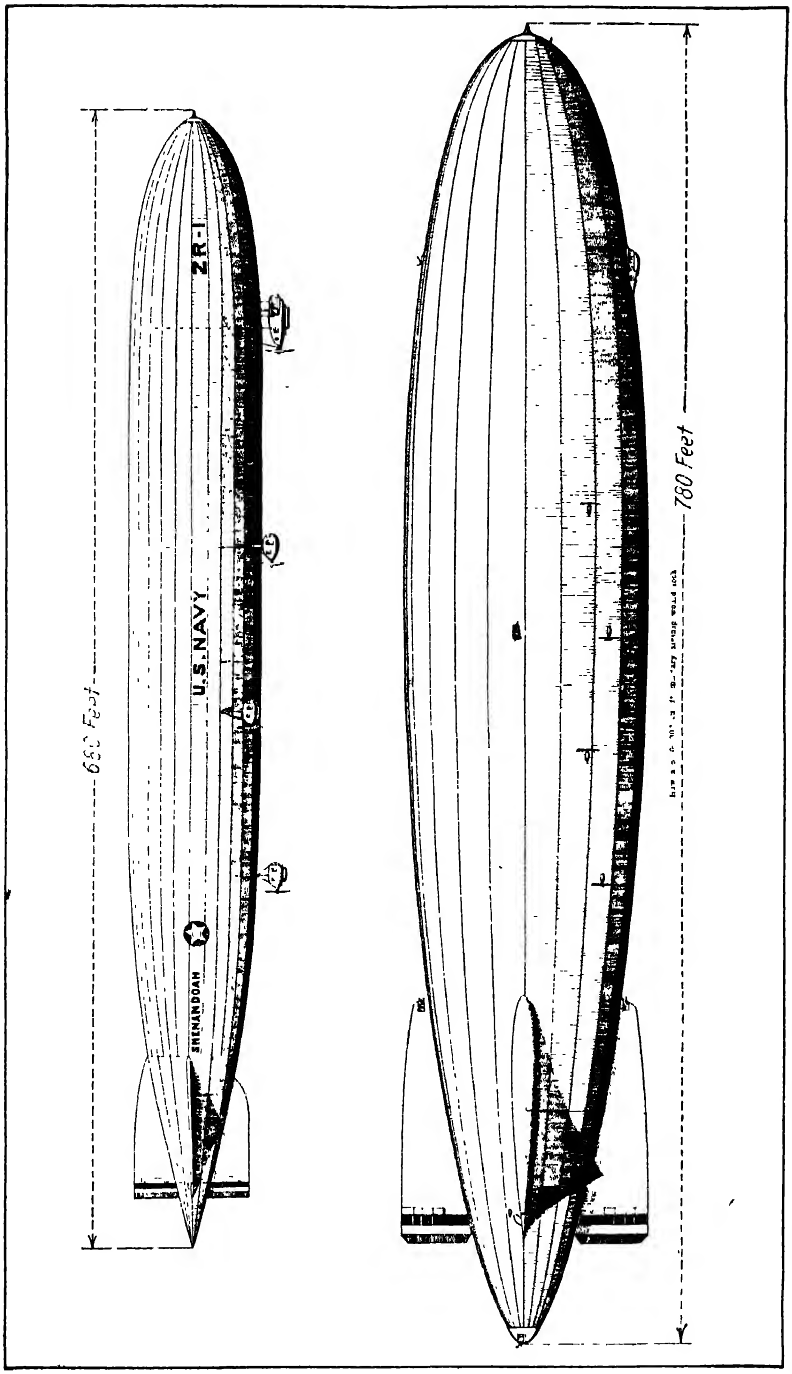


Fig. 322—Drawings Comparing the Size of the U. S. Navy Shenandoah or ZR1 with a Proposed Military Airship Having More than Three Times its Cubical Contents.

the most satisfactory results, although it must be remembered that all long exhaust manifolds are the greatest fire hazard on any airplane, as proved by the crash tests of the Engineering Division at McCook Field.

Metal propellers are coming into more general use and have many advantages over the laminated wooden type. They are stronger, are not subject to atmospheric conditions, can fly through rain and hail without damage or take-off through high grass, and are made with variable pitch, but they are slightly heavier and costlier than wooden propellers. There is no doubt of the superiority of the metal propeller, and its many advantages undoubtedly will appeal to the private owner and operator.

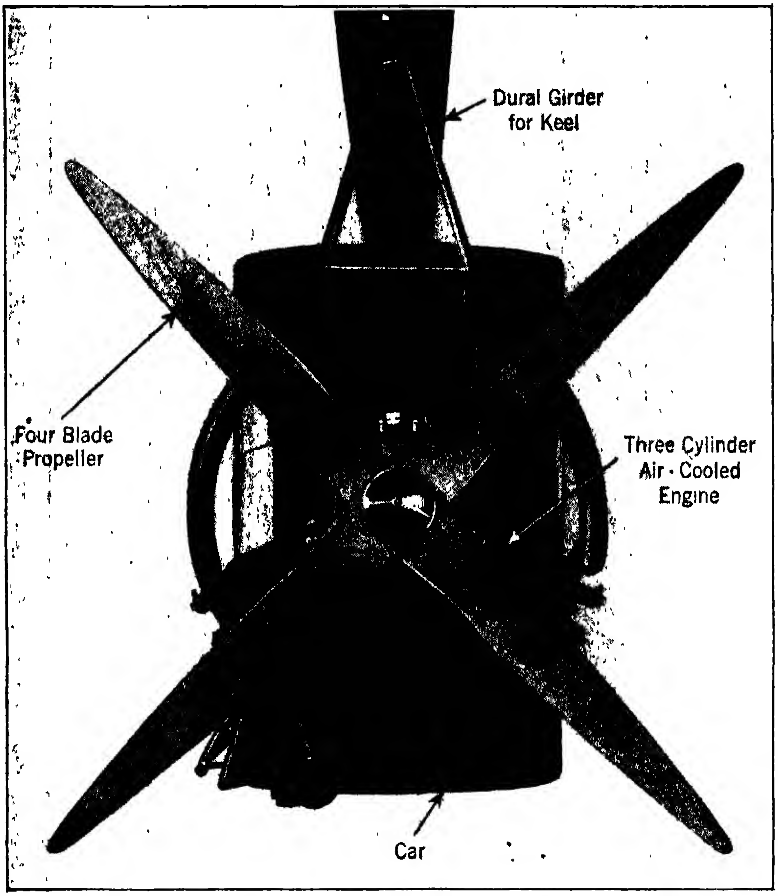


Fig. 323.—Rear View of Power Car of Small Non-Rigid Type Dirigible Showing Installation of Wright "Gale" Engine and Four Blade Metal Propeller.

The single-engine type of privately owned airplane can be built readily with the maximum of 250 horsepower and should be air-cooled. Whether the engine will always be radial and air-cooled is hard to predict; but we can rest assured they will be air-cooled, regardless of cylinder arrangements. More inquiries are received requesting information about our airplane equipment with an air-cooled engine than about our airplane equipped

with a water-cooled engine. Taking these inquiries as a criterion, we can readily interpret the desires of the public.

The old question of monoplane versus biplane is often resurrected and again is carefully laid aside without reaching a definite decision, although the biplane can be stored in a smaller hangar, is handled more easily and can be built lighter for the same factor of safety. The larger successful monoplanes today have either duralumin wings, with duralumin spars, such as the Stout airplanes, or wooden spars with veneer covering, such as the Fokker airplanes. Both are of the cantilever type. The old-type fabric-covered monoplane wings have not proved successful owing to their lack of torsional rigidity which produces fluttering when the fabric loses its tautness.

Biplane wings readily can be made to fold without any great difficulty in design or any need of stronger wing fittings, but a monoplane requires stronger fittings because the entire wing is supported only at one point

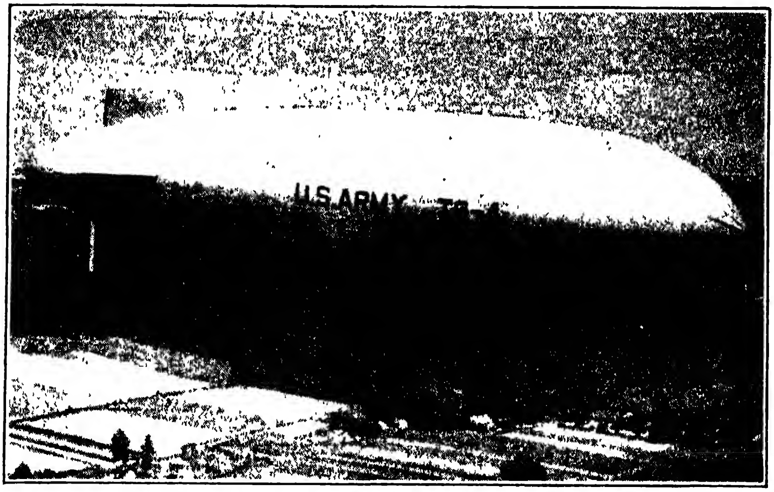


Fig. 324.—View of U. S. Army TC-4 Non-Rigid Type in Flight Taken from Official Photograph of U. S. Army Air Corps.

when folded back. Equipment with folding wings has been accomplished successfully for small monoplanes, but in the larger types the greater overhang of the wing leads to serious structural difficulties.

Stability in flight, while highly desirable to a limited degree, is not desired by the experienced pilots because it makes an airplane hard to control in rough air. Just enough stability so that an airplane can be set to fly 'hands off' in smooth air is sufficient, as, otherwise, the pilot must fight the 'bumps' and the airplane also in rough weather."

Geographical location and topographical conditions determine the airplane requirements of many prospective purchasers, and many inquiries are received from along the sea-coast regarding pontoon installations. Inquiries from the Great Lakes and the lake regions of Michigan and Minnesota are in regard to amphibians. As a sport type, the amphibian airplane offers many advantages, particularly as to storage facilities and the ability

to choose its own landing field. In fact, the amphibian has made the flying boat obsolete as a pleasure craft.

Performance need not be sacrificed in an amphibian as is proved by the performance of the Loening Amphibians, but in the interest of lighter construction and due to the arbitrary limitation of 250 horsepower, the hulls probably will be built of duralumin because of absence of water soakage,

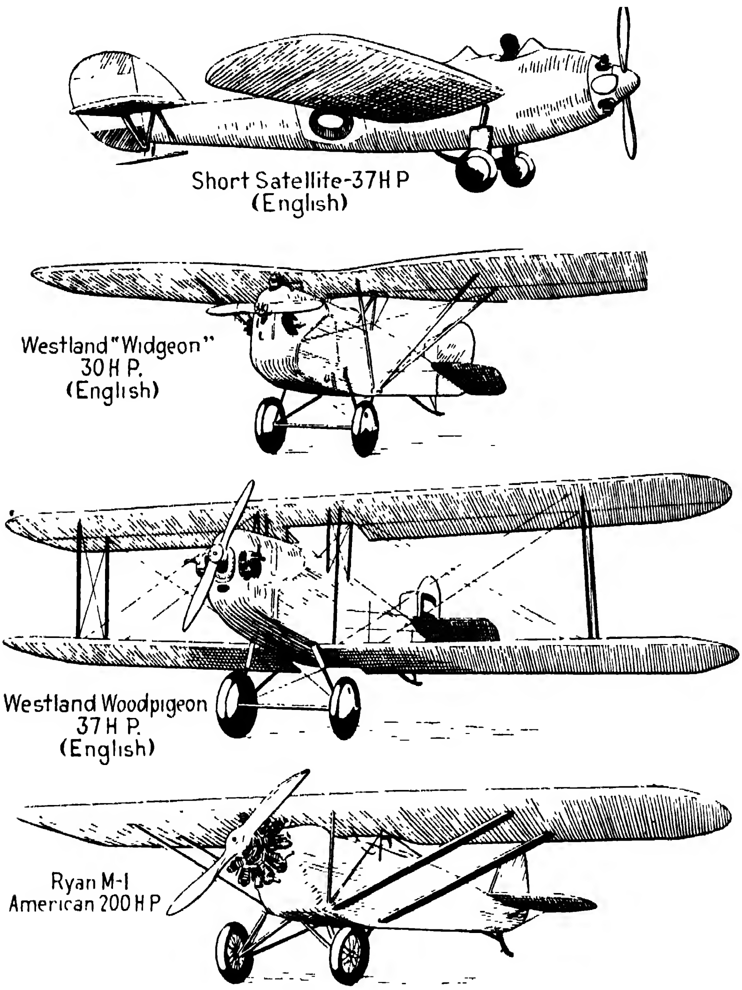


Fig. 325.—Typical Light and Medium Weight Airplanes. Three Upper Views Show Two English Monoplanes and One Biplane. The Ryan M 1 is an American Design of Braced Wing Monoplane.

which is unavoidable with a veneer hull. Interesting experiments are now being conducted with rubber covered veneer to reduce and possibly to eliminate this water soakage, but it is doubtful whether the added increase

in weight, with its correspondingly reduced performance, can offset the added cost of a duralumin hull.

Light Airplanes.—Attention has been directed for some time past to the development of low-powered airplanes and numerous very small and light types have been devised that have flown with motorcycle and small two-cylinder and three-cylinder air-cooled engines. When an engine having just barely the power requirements for flight is used, the airplane can be flown only at full throttle and every last bit of power the engine can produce is demanded. Modern small airplanes are flying with power loadings of about 30 horsepower and in some cases as much as 60 horsepower is provided. Engines in most light airplanes are greatly overloaded and do not provide any surplus power for emergencies. Owing to low power, the rate of climb is slow. Great care is needed in the design to secure adequate control surfaces. The structural design is extremely important as weight must be kept to a minimum. While calculations show that light airplanes may be built that will fly with as little as 10 horsepower, practical experience shows that at least 2.5 to 3 times that amount should be the minimum provided. To design a safe airplane that will fly with low power and carry two people of medium or average size calls for much study, ingenuity in design and considerable knowledge of the structural strength of materials. The usual wing loading for light airplanes is from 5 to 6 pounds per square foot. Descriptions of some typical forms follow from which the reader may get an idea of the characteristics of this type. The descriptions are some that have appeared in "Aviation" magazine, and the appearance of the planes may be seen at Fig. 325.

The Short Satellite.—This is nearly an all-metal monoplane lightplane with an all-duralumin fuselage of monocoque construction. The wings are of cantilever construction with wooden spars, duralumin ribs and fabric covered. Wing flaps extend over the entire span and serve both as ailerons and as camber changing devices. The undercarriage is of the Vee type with the front legs attached below the front wing spar root and the rear legs extending backwards to the bottom of the fuselage. The axle is of hinged type attached also to the bottom of the body. The engine is a twin-cylinder horizontally opposed A.B.C. Scorpion II of 37 horsepower. The general details are:

Span	34 ft
Length	23 ft. 9 in
Wing area	168 sq ft.
Weight loaded	1,060 lb.
Wing loading	6.4 lb./sq. ft.
Power loading (35 hp)	30.2 lb./hp.

The Westland Woodpigeon.—This is an equal wing biplane with dihedral and slight stagger and a single interplane bay. Wing flaps extend the entire length of the span of both wings and act as ailerons and camber changing devices. The wings fold about the trailing spar. The fuselage is of wood construction, the longerons being of spruce struts and swaged rod bracing and fabric covering. The undercarriage is of Vee type with a telescopic front leg in which a friction damping device is fitted. The tailplane,

which is of normal construction, is adjustable. The engine is an A.B.C. Scorpion of 37 horsepower. The general details are:

Span	27 ft.
Length	20 ft. 9 in.
Height	7 ft. 1 in.
Wing area	200 sq. ft.

The Westland Widgeon.—The fuselage and tail unit of this plane are almost identical with the similar parts of the Westland Woodpigeon. The machine is, however, a monoplane with a high parasol type of semi-cantilever wing. The wing is supported at the center by a cabane of six struts and is braced at about one-third of the semi-span on each side by means of Vee struts extending upwards from a single point on the lower longeron of the fuselage to the front and rear wing spars. The wing is of peculiar plan form, the chord being small at the center line and widening out to the point of attachment of the bracing struts and then tapering steadily to the wing tips which are rounded. The section of the wing, likewise, is peculiar in that it is thin at the center line, becoming thicker gradually towards the bracing strut attachment, finally tapering off towards the wing tips. The wing is of Airscrew 4 section. From the aerodynamic standpoint, this arrangement probably gives a very efficient wing while it certainly has structural advantages. The Widgeon, made the fastest speed in the Grosvenor Cup Handicap race, the figure being 105.5 miles per hour although even this did not give it a place in the finish since it was evidently heavily handicapped. The engine now fitted is an Armstrong-Siddeley Genet. The general details are:

Span	30 ft. 8 in.
Length	20 ft.
Height	6 ft. 11 in.

Ryan M1 Monoplane.—This is not a light plane in the sense that it has been designed solely for low power, but it is a good example of a practical machine in which good performance is sought.

The wing which is 36-foot span is mounted above and directly onto the fuselage structure, although the peculiar cockpit arrangement, with the fuselage covering cutaway, gives the general appearance of the existance of center section struts. This arrangement gives the pilot and passenger a very clear view ahead and to each side.

The fuselage is constructed of welded chrome-molybdenum steel tubing, protected by Lionoil and covered with fabric. No wires are needed for bracing purposes, the Warren truss system being employed. The tail surfaces are also of steel tube construction, and the stabilizer is adjustable from the pilot's seat. The tail skid is constructed of spring leaf steel and is steerable, rendering ground maneuvering greatly facilitated. The under carriage is a normal split axle type constructed of steel tubing with a wide track.

The engine mounting and engine are completely removable by taking out four nickle steel bolts. This makes possible the use of several different types of engines by simply changing the mountings, which can be done

in about twenty minutes. Thus, airline and air mail operators using the plane need not necessarily keep several planes in reserve for engine overhaul, since extra engines may be mounted and maintained ready for installation at short notice with connections ready for instant attachment. The power plant is a Wright Whirlwind 200 horsepower radial air-cooled engine.

The wing is of moderately thick section built in one piece. The spars are of box type with special two-ply mahogany walls with the grain running at 45 degrees. The leading edge is reinforced with plywood. The wing is braced with two struts of streamline steel tubing on each side of the

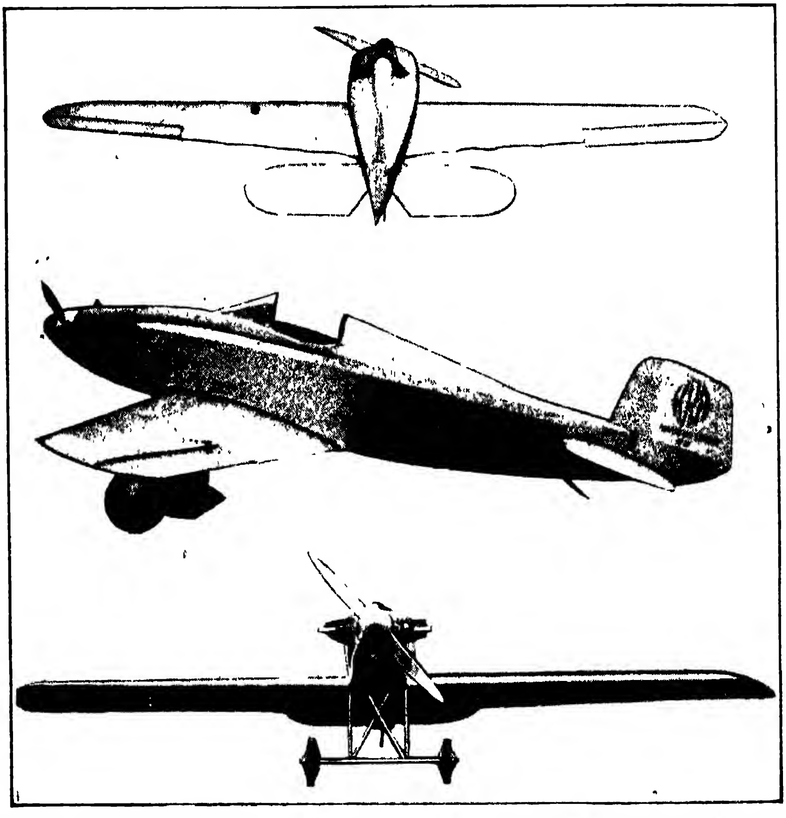


Fig. 326.—Views Showing Construction of the Kreider-Reisner Light Monoplane.

fuselage, supporting the wing at points approximately one-half the semispan from the wing tips. The streamline strut section is that of an airfoil. In actual test, the Ryan M1 has carried a pay-load of 644 pounds off the ground with a run of 390 feet, climbed 2,000 feet in 2 minutes and attained a maximum speed of 135 miles per hour. This monoplane, in a modified form having a greater wing spread was the first to make the flight from New York to Paris, piloted by Captain Charles Lindbergh on May 20th and 21st, 1927. While the plane was designed for a Whirlwind engine, an OX5 has been fitted and also a Hispano-Suiza of 150 horsepower. The performance is given in the following table:

PERFORMANCE OF RYAN M-1 WITH WHIRLWIND, 200 hp.

Pay-load	600 lb.
Cruising speed	115 m.p.h. at 1500 r.p.m.
High speed	135 m.p.h. at 1800 r.p.m.
Landing speed	45 m.p.h.
Initial rate of climb	1,200 ft. first minute
Climb in 10 min.	9,000 ft.
Climb in 39 min.	17,500 ft.—(service ceiling)
Absolute ceiling	19,000 ft.
Cruising range	500 miles

K.R.A. Light Monoplane.—This interesting machine is the product of the Kreider-Reisner Aircraft Company, of Hagerstown, Md. It is a low wing monoplane of very good design. The views at Fig. 326 show the general features of construction. The specifications follow:

Span	20 ft.
Wing Area (including Aileron and Axle Airfoil)	60 sq. ft.
Area of Ailerons	6 sq. ft.
Area of One Piece Longitudinal Tail Surface	10 sq. ft.
Area of One Piece Vertical Tail Surface	4½ sq. ft.
Angle of Incidence	3½ degrees
Airfoil Section	M6
Propeller (Curtiss Reed Metal)	5′ diam.
Engine—Wright-Moorehouse	30 hp. at 2500 r.p.m.
Wing Chord at Root	4′
Wing Chord at Tip	2′
Length Overall	15′ 2″
Height Overall	4′ 6″
Weight Empty	289 lbs.
Weight with Gas and Oil for Races	320 lbs.
Weight of Pilot	170 lbs.
Total Weight in Race	490 lbs.
Landing Speed	48 m.p.h.
High Speed	112 m.p.h.

Pander (Dutch) Light Plane.—This very efficient light airplane has made several good cross country flights, among which was one from Rotterdam, Holland to Barcelona, Spain. Its appearance is given in perspective and plan drawings at Fig. 327. This machine is a high wing cantilever monoplane. Great pains have been taken with the streamlining and the good performance achieved with such low power is very largely due to this. The wing is in one piece and rests on the top longerons, each spar being secured by long U-bolts carrying yokes above the spar. The spars are of box section, with spruce flanges and three-ply walls. The front spar is of somewhat unusual arrangement and forms a box with the plywood covering of the leading edge. The curved wing tip is fairly thick, and is built up of a great number of laminations afterward spindled out to an approximately semi-circular section.

The machine is powered with an Anzani three-cylinder, 122 cubic inch, 25 horsepower engine. The fuel tanks are in the wings and the gasoline supply is by gravity. The landing gear is of the axleless type. The wheels are carried at the ends of two streamline steel tubing Vees attached to the upper longerons at the same point as the spars and another member running

to the center of the bottom of the fuselage. The tail skid is sprung and is steerable. The fuselage is a monocoque, consisting of light longerons and hoops with a three-ply covering. Actually the fuselage is flat sided, but the turtle back and bottom fairings merge into it so gradually that the impression is given that it is elliptical. The pilots cockpit is placed between the wing spars, the curved coaming being placed around the cockpit after the wing is in place. Stick control is provided and in place of the rudder bar there are two tubular pedals with heel rests and toe guards.

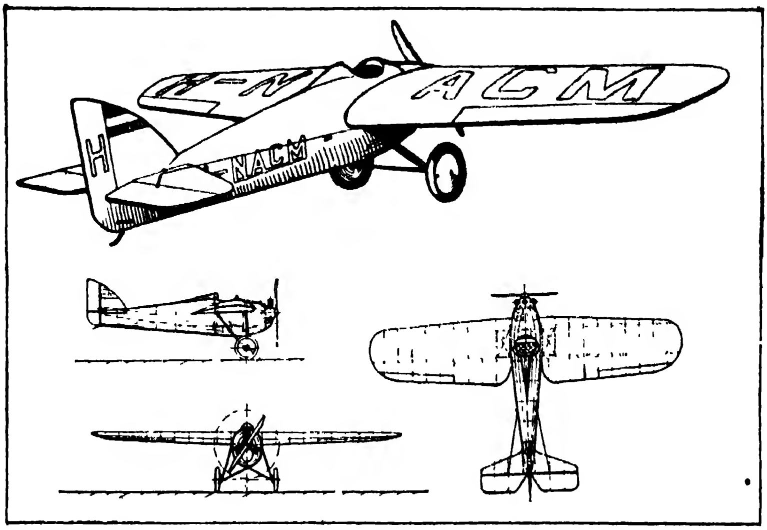


Fig. 327.—Perspective Drawing, Plan and Elevations of Pander Single Seat Monoplane.

SPECIFICATIONS

Length	16 ft. 3 in.
Height	5 ft. 5 in.
Span	26 ft. 3 in.
Area	116 sq. ft.
Weight, empty	420 lb.
Weight, fuel	95 lb.
Weight, pilot	165 lb.
Total weight	680 lb.
Wing loading	5.85 lb./sq. ft.
Power loading	27.2 lb /hp.
Maximum speed	75 mi./hr.
Minimum speed	31 mi /hr.

Medium Weight Planes.—While it is not possible in a book of this scope to describe all airplanes that have been built, it seems desirable to describe and give the specifications of typical examples. By far the greatest number of airplanes built are in the medium weight class designed to carry from two to five passengers and using engines of from 100 to 200 horsepower. Of course, the airplanes used in the military services are provided with high-powered engines because exceptional performance is demanded. For commercial use, however, such speed and climb characteristics as are essential in military specifications may be replaced by more moderate

speeds and the use of the relatively low-powered engines makes for economical maintenance and operation. Steel tube fuselages are used in many of these types, but there is a wide variation in practice between different designers as to wing and horsepower loadings. The wing loading varies from 6 to 10 pounds per square foot, the horsepower loading will average approximately 20 pounds per horsepower. The characteristics of some single-engine types will now be described.

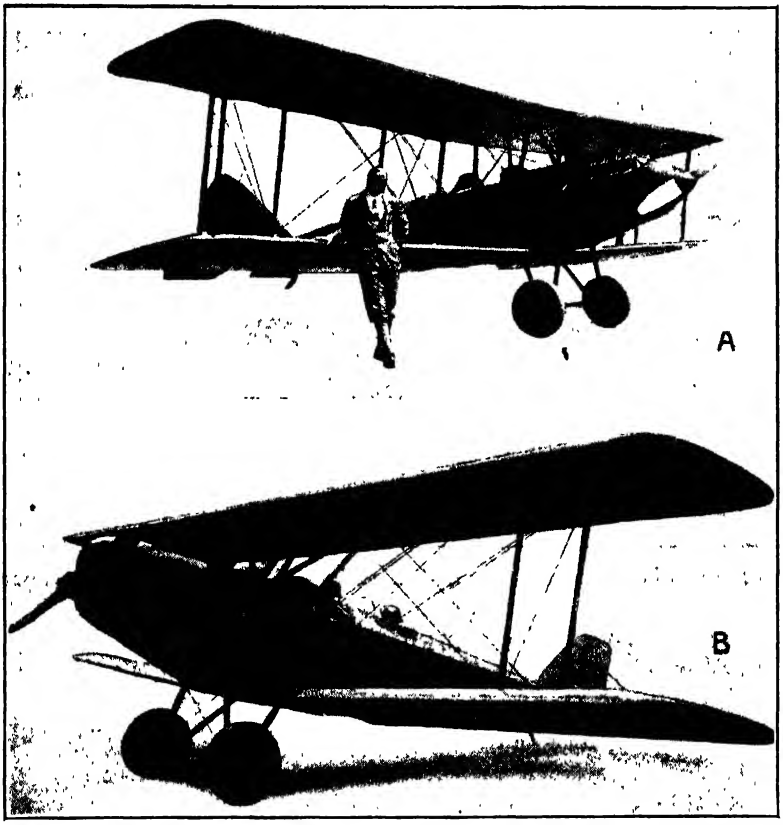


Fig. 328.—Harold F. Pitcairn and the Orowing Biplane with Curtiss OXX5 Motor of his Design in which he Completed the 1926 Airplane Reliability Tour at A. The Pitcairn Fleetwing shown at B.

Pitcairn Orowing.—This biplane machine, which is shown at Fig. 328 A is said to have good inherent stability and to react readily to the controls. The maximum flying speed is not high, but is ample for the purpose for which the airplane is intended, the OX5 motor is used for power. The flying speed is a maximum of 90 miles per hour, the cruising speed is 78 miles per hour and the landing speed is 40 miles per hour which makes this airplane a very good training ship and for general civilian flying. Dual control is standard equipment. Owing to the location of the passenger cockpit the longitudinal balance of the ship is not affected by varying load, this reducing the strain on the pilot. Even at stall speed, enough aileron surface has been pro-

vided to permit accurate control. A carefully considered design has provided for the ready removal of elements that need periodical attention. The tail skid is removable by pulling one bolt, and bronze bushings for the tail skid post may be easily replaced when worn. The tail skid shock absorber unit is also removable independently by taking out one bolt. Gasoline tanks can be quickly released, and may be removed without disturbing the cowling. The cowling is quickly detachable, and when it is removed the mechanic has unobstructed access to all parts of the motor.

SPECIFICATIONS, PITCAIRN OROWING

Span, upper wing	36 ft.
Span, lower wing	35 ft. 11¾ in.
Chord, both wings	60 in.
Gap	64⅞ in.
Stagger	14¾ in.
Incidence, both wings	2½ deg.
Dihedral, both wings	1½ deg.
Length overall	26 ft. 2 in.
Height overall	9 ft. 2½ in.
Weight empty	1345 lbs.
Useful load	755 lbs.
Passengers	340 lbs.
Pilot	170 lbs.
Gasoline	180 lbs.
Oil	32 lbs.
Water	33 lbs.
Weight loaded	2100 lbs.
Area of wings	338.37 sq. ft.
Area of horizontal tail	33 sq. ft.
Area of vertical tail	13 sq. ft.
Power	90 hp. at 1400 r.p.m.
Wing loading	6 2 lbs. per sq. ft.
Power loading	23 2 lbs. per hp.
Wing section	Modified RAF-15

The Pitcairn Fleetwing.—As originally conceived, the Pitcairn Fleetwing the latest model of which is shown at Fig. 328 B was to be used for the sole purpose of carrying passengers on short flights. While this purpose has been kept foremost in the minds of the designers, it was also deemed advisable to fit the plane to be used as a short radius cross country machine for carrying passengers, express or mail. Where the latter purpose could be incorporated without sacrificing the primary object, it was done, and the Fleetwing is serviceable for short hops from the flying field for cross country flights of 3½ hour duration with four passengers. By removing the two passenger seats a cargo space of 32 cubic feet is made available, which will contain approximately 200 pounds of parcel post matter or 800 pounds of letter mail. It is believed that the Fleetwing is the only plane built for the sole purpose of carrying out 15 or 20 minute hops with passengers, and incorporated in the design are the features of a quick take-off, rapid climb, and slow landing speed, without making high speed the primary consideration as is frequently the case.

The fuselage proper, without cowling, is of trapezoidal section, the longer of the two parellel sides being at the top. This allows ample room across the shoulders of the passengers and for their feet and, at the same

time, maintains cross-sectional area as low as possible. The section of the fuselage top fairing is flat-sided, giving good vision and easier installation of windshields than would be the case in a curved fairing. For ease of control on the ground a steerable tail skid is installed and is operated in conjunction with the rudder.

The wing structure is of the single-bay biplane type with a pronounced stagger. The upper and lower panels on any one side of the plane are made identical, with the exception of the strut and wire fittings, arrangements being made for reversal of these. The wings are of wood construction with I-section spars of spruce and lattice ribs of spruce and plywood. Compression ribs and sidewalk ribs are of box section with spruce cap strips and plywood webs. Two box ribs, with a plywood cover plate, are inserted at the interplane strut point. The use of box ribs tends to make the panels tortionally very rigid.

The center section panel is of construction along similar lines to the outer panels and contains a 15 gallon gasoline tank. This tank is on one side of the fore-and-aft center line and provision is made for the installation of another tank opposite.

The wing struts are of circular section steel tubing with spruce fairing, but it is planned to use streamline duralumin tubing for these parts as soon as it can be procured from the manufacturers. All of the interplane struts, with the exception of the middle strut of the N, which fixes the gap, can be adjusted without being removed from the plane, thus shortening, to an appreciable extent, the time required to complete the rigging. Streamline wires are used throughout, the flying wires being double and the landing wires, single. Two of the flying wires are crossed to take care of the drag and anti-drag forces in flight. Rigging details of the wings are as follows: the upper wing is set at an angle of incidence of 1½ degrees and the lower wing at ½ degree, giving an open décalage of 1 degree. The tips are washed-out to reduce any yawing tendency.

The ailerons, which are unbalanced and identical on each side of the plane, are hinged directly to the rear spar. The aileron beam is of box section with spruce webs and plywood cover plates, the hinge eyebolts passing through both beams with a spacer spool between the webs. Aileron control cables are enclosed and run through the wings in aluminum tubing to facilitate replacement. Ball bearing pulleys are used in the control system.

GENERAL CHARACTERISTICS

The general features of the machine are as follows:

Span, upper wing	38 ft.
Span, lower wing	33 ft. 1 in.
Chord, both wings	62 in.
Gap	6 ft. at center
Stagger	25 in.
Incidence, upper wings	1½ deg.
Incidence, lower wing	½ deg.
Dihedral, upper wing	0 deg.
Dihedral, lower wing	2 deg
Length overall	25 ft. 11 in.
Height overall	9 ft. 10 in.

Weight, empty	1802 lb.
Useful load	1110 lb.
Passengers	610 lb.
Pilot	160 lb.
Gasoline	210 lb.
Oil	40 lb.
Water	60 lb.
Weight loaded	2912 lb.
Area of wings	350.67 sq. ft.
Area of horizontal tail	39.63 sq. ft.
Area of vertical tail	15.32 sq. ft
Power	160 hp at 1750 r.p.m.
Wing loading	8.3 lb./hp.
Power loading	18.1 lb./hp.
Wing section	USA-27

PERFORMANCE

(Certified by National Aeronautical Assn.)

Light with pilot, oil, water and 32 gals. gasoline and without passengers:

Maximum speed at ground	109.8 m p h.
Ceiling	15,886 ft.

Loaded, with pilot, oil, water, 32 gals. gasoline and with 700 lbs. of sand:
(Total weight 2961 lb.)

Maximum speed at ground	106.2 m p.h.
Ceiling	12,145 ft.

The Buhl-Verville CW3.—This is a very efficient and serviceable biplane that can be used for passenger carrying, express service, aerial photography, crop dusting and training. The wing cellule is of the biplane type, without stagger and the wings may be folded back, as shown at Fig. 329 so the machine will occupy minimum hangar space. When folded, the space required is but 9 feet by 13½ feet by 25 feet. The wings can be folded back in twelve to fifteen minutes. When extended, the span is 35 feet. The fuselage is of tubular steel construction welded into an integral structure, the tubing being an ordinary grade that can be easily secured on the open market. Two cockpits are provided, the forward one is for the passengers and will accommodate two people sitting side by side. The stabilizer is adjustable as is the vertical fin which may be set to counteract propeller torque reaction.

One of the most interesting features of this plane is the wide track axleless landing gear. This not only reduces the resistance which is present in an ordinary axle type when taking off, due to high grass, but also lessens the possible chance of accident when landing on rough ground. The wide track furthermore, reduces the possibility of a wing tip becoming damaged in a poor landing. Shock absorbers are of the Oleo rubber disc type. Under loading conditions, these rubber discs are in compression and an internal perforated plunger piston simultaneously travels into a loaded oil chamber at the lower end of the strut. This absorbs the impact energy and neutralizes the effect of the rebound which is so prevalent with the ordinary rubber sprung shock absorbers. It cushions the landing shocks to the extent of saving the whole airplane structure from the strains which are occasioned by shocks in bad landings over rough ground.

The CW-3, as illustrated, is equipped with a 90 horsepower Curtiss OX5 engine, cowled under a quickly detachable cowling. A 40 gallon gasoline tank, sufficient for five hours flight, is situated immediately back of the engine, in the fuselage and ahead of the passenger cockpit. The gasoline system is of the gravity feed type. The oil, in the case of the OX5 model, is carried in the bottom half of the engine crankcase. The radiator is located immediately under the engine, and is of the underslung type. It is provided with shutters which are manually operated by the pilot in flight. A Reed duralumin propeller is fitted.

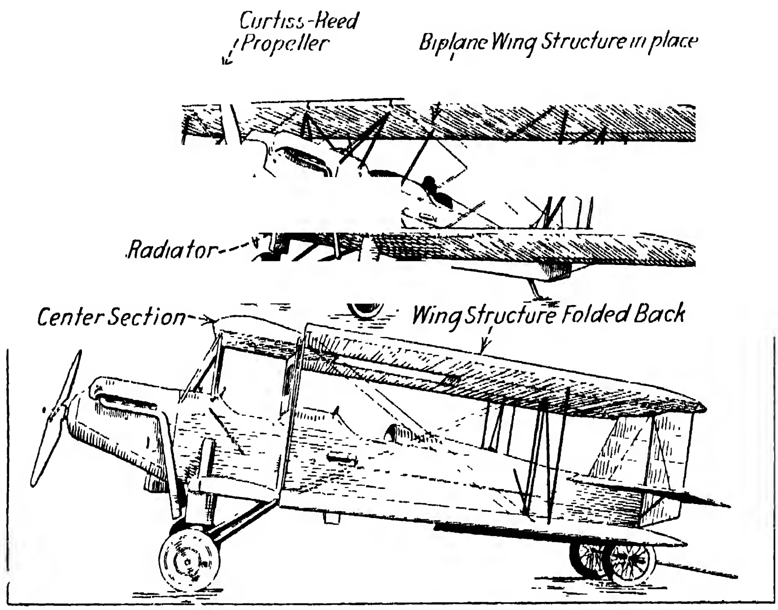


Fig. 329.—Views Showing Buhl-Verville Airster, a Three Place Biplane of Modern Design. Upper View Shows Front with Wing Cellules in Place for Flying. Lower View Depicts Wings Folded Back for Storage in Small Hangar.

The design of this machine incorporates high factors of safety and is, generally speaking, in accordance with the demands of the Aeronautical Safety Code. The minimum factors of safety to which the machine was designed are as follows:

High incidence condition	8
Low incidence condition	5½
Inverted flight condition	3½
Landing condition	7
Ribs, in medium incidence condition	6¼
Height of free drop of shock absorbing unit and landing gear	26 in.
Loads for ailerons and horizontal tail surfaces	35 lb./sq. ft.
Loads for vertical tail surfaces	30 lb./sq. ft.

SPECIFICATIONS

The main characteristics of the airplane are as follows:

Span, maximum	35 ft.
Length, maximum	25 ft.
Overall width with wings folded	13½ ft.
Height, maximum	9 ft.
Area of wings	300 sq. ft.
Area of ailerons	28 sq. ft.
Area of stabilizer	21 sq. ft.
Area of elevators	16½ sq. ft.
Area of fin	5¾ sq. ft.
Area of rudder	8½ sq. ft.

With OX5 engine installation:

Weight empty	1380 lb.
Weight fully loaded	2150 lb.
Endurance at full throttle	5 hr.
High speed	95 m.p.h.
Low speed	40 m.p.h.

With Wright Whirlwind (200 horsepower) engine installation:

Weight empty	1415 lb.
Weight fully loaded	2300 lb.
Endurance at full throttle	3½ hr.
High speed	133 m.p.h.
Low speed	45 m.p.h.
Rate of climb at ground level	900 ft./min.

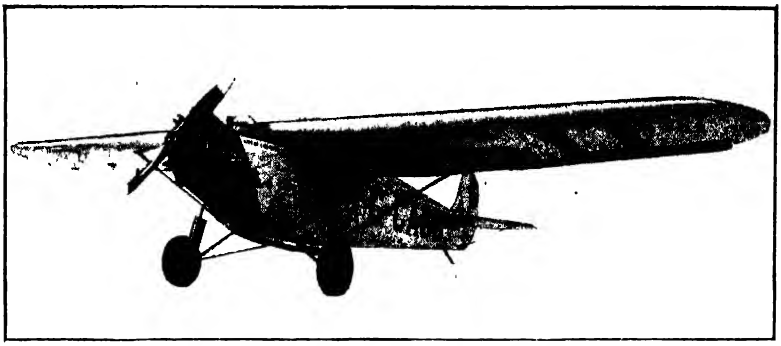


Fig. 330.—Fokker Universal Monoplane Used by Western Canada Airways, Ltd., is a Cabin Type Capable of Carrying a Pilot, Four Passengers and 80 Pounds of Baggage for 500 Miles on One Filling of Fuel Tanks.

Fokker Universal Type.—The monoplane shown at Fig. 330 is a cabin type that can be used for many purposes as it can be mounted on wheels, as shown or on pontoons for alighting on water and skis for snow and ice. It will carry a pilot, four passengers and 80 pounds of baggage 600 miles or a pilot and six passengers for 300 miles. It can be used for photography, surveying and mapping. It will carry a pilot, photographer and equipment for seven hours with a ceiling 16,000 feet. It has been used for crop dusting, forest fire patrol, prospecting, exploring and freight and passenger trans-

portation. The wings are of semi-cantilever form, built in one piece that is 47 feet long and is a wood rib construction covered with veneer instead of fabric. If desired, the wing may be made in two pieces. The fuselage is of steel tubing. Two fuel tanks have a total capacity of 78 gallons and there are two entirely separate pipe lines, provided with shut-off cocks within reach of the pilot. The pilot's compartment is of the open cockpit type.

Both in flying qualities and in structure, maximum safety is assured. The "Universal" does not nose dive or spin when stalled, but sinks on an even keel, while remaining under full control. Response to all controls at all speeds is instantaneous. Heavy triangulated steel structure around the cockpit and cabin provides maximum resistance against collapse, together with impossibility of splintering; quick take-off, good climb and low landing speed, exceptionally strong landing gear, with 10-foot track, high factors of safety throughout and complete freedom from fire hazard are further safety features.

In view of the numerous different commercial purposes for which an airplane of this type, size, and performance can be used, the fuselage has been laid out so as to provide the maximum unobstructed cabin space, which can be divided into passenger and freight or baggage compartments, according to individual requirements. As standard equipment, four comfortable passenger seats, with plenty of "leg" room, are fitted in the forward part of the cabin, behind which ample baggage space is left. If desired, however, two more seats can be fitted in this space, or a part of it can be equipped as a lavatory and toilet.

The standard interior finish is simple but neat, being partly carried out in imitation leather and partly in Duco finished fabric, reinforced with veneer where necessary. These materials are easily cleaned and renovated. They also permit easy stripping for inspection and overhauls without destruction. The proportions of the cabin lend themselves excellently to conversion as an ambulance plane. With this arrangement, two or three stretchers and seats for two attendants can be installed. For carrying mail or express, and, when specified, the whole or any part of the cabin space can be completely walled with heavy veneer or metal. Sliding windows of ample size are provided. The door is of convenient size for entry by one step from the ground. It is solidly built and will stand up under the slamming and blowing which is inevitable in hard commercial use. The inside dimensions of the cabin and baggage space are 9 feet length, and 3 feet, 5 inches width, while the height varies from 5 feet, 6 inches at the front end to 4 feet, 6 inches at the rear of the baggage space. The total available load space is 146 cubic feet. A cabin heater, taking in clean air heated by the exhaust pipe, can be installed when desired.

In the Fokker "Universal" plane the most perfect vision for the pilot is provided. Seated ahead of the leading edge of the wing, the forward, right and left, overhead, downward, and rear visions are entirely unobstructed. To the rear of each side, under the wings, the vision also extends back over a capacious angle. The cockpit is well screened, comfortable, and roomy. It is well protected by the steel structure, and in case of

"nosing over" the pilot's head is protected by the wing and fuselage structure and the engine. An emergency exit is provided.

Stick control and rudder pedals of the straight pull swinging type are fitted. All pulleys are directly visible. The only control cables running over pulleys at a 90 degree angle are those to the ailerons. Rudder, tail skid, and elevator cables only run over one bakelite pulley each, and at very "flat" angles. The controls all work very lightly, both mechanically and in the air. The instruments are set in the usual type of dash in front of the pilot. The standard equipment furnished with every plane includes: tachometer, oil pressure gauge, oil thermometer and altimeter. There is ample room for compass, bank and turn indicator, and airspeed indicator, which are fitted as extras according to individual requirements.

By means of a simple and positive screw gear of substantially the same design as has been used on a number of the latest types of Fokker aircraft, the incidence of the stabilizer is adjustable from the pilot's seat.

The rudder and elevator are balanced and very effective at all speeds, even below the stalling speed.

The most recent development of the Fokker steerable tail skid is fitted. This skid arrangement has given full satisfaction on the five latest types of Fokker military and commercial aircraft. The skid is made of chrome nickel steel tube and is practically unbreakable. It has a detachable shoe, consisting of a simple manganese steel casting, which is held in place by two bolts. The shock absorbers are rubber rings, easily slipped into place under no tension, and tightened by turning a nut.

The method of steering is novel, and the movement, although very effective, is "irreversible." The result is that there is no tendency to involuntary "ground looping" and taxiing in a cross wind is perfectly easy.

SPECIFICATIONS

Dimensions.

Span.... 47 feet   Length ... 33 feet   Height.... 8 feet

Useful Load.

Pilot	180 lbs.
Pay-load (normal circumstances, for quick take-off)	800 lbs.
Fuel (80 gallons) and Oil (5 gallons) for six hours at cruising speed	520 lbs.
Total useful load	1,500 lbs.

Performance with Full Load

High speed	118 m.p.h.
Cruising speed (1,500 r.p.m., 115 hp)	95 m.p.h.
Landing speed	42 m.p.h.

Climb—3,300 feet	5½ min	10,000 feet	21 min.
6,500 feet	12 min.	Ceiling	14,000 feet

Wright-Bellanca Monoplane.—This cabin plane, which is shown at Fig. 331 made an endurance record in April 1927 by remaining in the air over Long Island for 51 hours and 31 minutes, piloted by Messrs. Bert Acosta and Clarence Chamberlin. This performance was made possible because the plane performs exceptionally well with low power.

In the design of the airplane, every provision has been made for maximum safety, including low landing speed, perfect vision, elimination as far as possible of the fire hazard, exceptionally long gliding angle of 12½ to 1, and excellent controllability at low speed. With the high position of the wing and the wide wheel tread, landing on rough ground is greatly simplified. The high speed of the Wright-Bellanca plane is 132 miles per hour, while it cruises comfortably at 100 miles per hour. The initial rate of climb is 900 feet which, even with full load, should enable quick climb from small fields. The plane seats five passengers comfortably and, if necessary, one more passenger may be carried in lieu of baggage. For express and mail carrying, a large cabin space of 122 cubic feet gives good cargo room.

The fuselage was made in three sections. The use of highly complicated fittings has been avoided as far as possible throughout the entire design. The engine mount is a tubular steel construction hinged to the fuselage, enabling it to be readily swung to one side for inspection purposes and adjustments necessary to the rear parts of the engine. The lubricating system is arranged with the oil tank carried in the engine mount so that oil connections need not be dislodged in the event of engine adjustments being necessary.

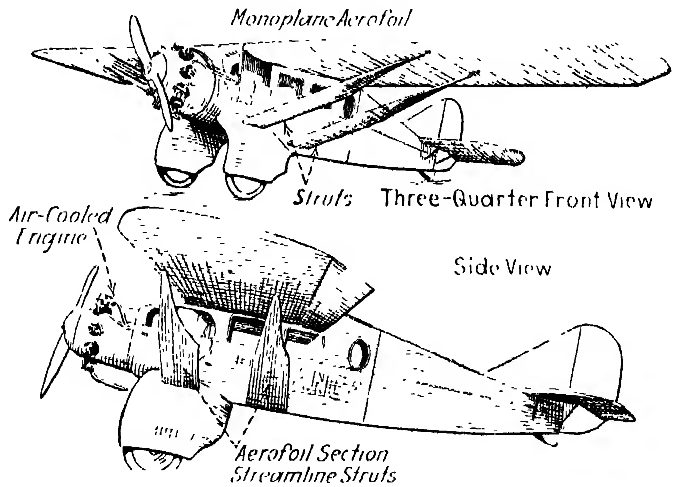


Fig. 331.—Three-Quarter Front and Side Views of the Wright-Bellanca Cabin Monoplane. Note Stream Lining of Wheels and Bracing Struts. Attention is Directed to Complete Enclosure for Pilot as Well as Passengers.

The fuel system, for simplicity, is of the straight gravity feed type with the fuel tanks in the wing, feeding directly to the engine and equipped with a quick shut-off valve. Incidentally it may be mentioned that in the Wright Whirlwind engine, the carburetor is below the lower cylinders and in this particular airplane design the carburetor is carried outside the engine cowling, which, in spite of possible minor disadvantages, possesses the added feature of aiming towards the reduction of fire hazard.

The wing construction is simple and conventional. The two spars are

spruce and of solid I-beam section. The ribs are also spruce, bass-wood and balsa, with triangular braces, making a very strong and light combination. This type of rib was tested to over 800 pounds before breaking. For a load factor of 7, only 375 pounds test load is required. Their weight is 12 ounces each. All the ribs are the same, with exception of one, at the tips, which is tapered. The covering of the wing is fabric, treated with seven coats of dope and one of Valspar. The wings are pin jointed to center section of fuselage.

The Bellanca Struts are of medium lift, aerofoil section, and the inner ends of these struts are attached to the body and the outer ends, to the cantilever points of the main wing spars, taking at the same time, the landing and the flying loads. Their lifting capacity is enough to carry more than their own weight, with the additional advantage of assisting effectively, the lateral balance of the plane, through their exaggerated dihedral. The load factor of the Bellanca struts is 12. They are made of straight grained birch, I-beam section and of spruce and bass-wood ribs. The leading edges are made of grooved balsa, protected by spruce and the covering is fabric, also treated with seven coats of dope and one coat of Valspar.

The power plant, the cabin and the tail are three complete separate units, which can be readily separated, one from the other, thus making it possible to replace any one of them. The engine mount weighs only 13½ pounds and between it and the motor is a duralumin fire-wall, which carries the cowl of the engine. The engine mounting, engine, oil tank and the cowl, form a complete unit, which can be quickly detached from the fuselage by removing 4 pins. By removing two pins and disconnecting throttle, spark and fuel line, the engine can be swung back on a hinge. The fuel tanks are welded sheet aluminum, located one in each inner extremity of the main wings with a total capacity of 63 gal. The gasoline and the gauge lines are of copper tubing and are located to be easily accessible. With the oil tank in the engine section, gravity fuel feed, and no water, the plumbing is minimized.

The center section of the fuselage is built with ash longerons and bulkheads, covered with mahogany plywood and is upholstered in mohair, while the tail section is made of welded chrome molybdenum tubing and is attached to the cabin section by 4 pins. The tail skid is of birch and is located entirely outside of the body and can be easily attached and detached while the shock absorber is also outside.

There are nine windows in the cabin, three large and one small on each side and one large one in the front, giving the pilot, as well as the passengers, excellent vision. The landing gear is of cantilever construction, somewhat novel in appearance, and is built of duralumin and chrome molybdenum tubing. It is completely enclosed in a streamline duralumin covering. Its resistance, as a result of the fairing, is claimed to be much less than the ordinary type of landing gear. The shock absorbers are readily rewound, being accessible in spite of the unusual undercarriage construction. The stabilizer is a non-lifting section and adjustable in flight. All the tail units are constructed of spruce, bass-wood and ash, and covered with fabric, doped and varnished.

SPECIFICATIONS

Span	45 ft.	Wing Area	272 sq. ft.
Chord	6 ft. 7 in.	Fuel capacity	63 gal.
Length	24 ft. 9 in.	Oil	5½ gal.
Height	8 ft. 5 in.	Weight empty	1,790 lbs.

Weight with gasoline, oil and pilot	2,380 lbs.
Weight including pay-load of five passengers	3,230 lbs.
Weight of pay-load	850 lbs.
Weight per hp. with gasoline, oil and pilot	11.9 lbs.
Weight per hp. with pilot and 850 lb. pay-load	16.1 lbs.
Weight per sq. ft. with gasoline, oil and pilot	8.75 lbs.
Weight per sq. ft. with pilot and 850 lb. pay-load	11.8 lbs.

The successful flight of Clarence D. Chamberlin and Charles A. Levine in a Wright-Bellanca monoplane, Columbia, from New York to Berlin, Germany, following closely upon the notable flight of Captain, now Colonel Charles Lindbergh from New York to Paris, France was a remarkable one in that it just added one more honor to an airplane that had already made some previous records of note and which had a flying time of over 200 hours in the air before it took off on its 3,900 mile trip across the Atlantic. The Spirit of St. Louis, the plane piloted by Lindbergh does not differ in essentials of design and used the same type air-cooled motor as was used by the Wright-Bellanca, a design which antedated that of the Ryan monoplane by several years.

This monoplane, built to Mr. Bellanca's design by the Wright Aeronautical Corporation in 1926 and powered with a Wright "Whirlwind," nine-cylinder, air-cooled, radial engine, is the same plane used by Chamberlin and Bertrand B. Acosta in setting up a new endurance record in April, 1927, it is the same plane which won first speed and efficiency honors at the National Air Races in Philadelphia in the fall of 1926 and a plane of the same type won the highest efficiency prize for commercial planes at the National Air Races at Mitchel Field in 1925.

The New York-Berlin plane is not an experimental design in any way. Early this year it was employed in a trial trip from New York to Washington carrying a full load of five passengers and the pilot for the purpose of obtaining relative cost-of-operation figures, which were surprisingly low. The only change which was made in the plane for the trans-Atlantic trip was installing extra fuel tanks in the cabin to replace the chairs ordinarily located there and the addition of the necessary instruments for the long voyage. The wing construction of the plane is conventional and the wings are braced externally by the well-known Bellanca struts, two on each side, whose lift not only more than compensate for their weight but whose marked dihedral adds considerably to the lateral stability of the plane. The fuselage is constructed in three sections made up of chrome-molybdenum steel tubing. Vision is exceptionally good because of the high placed wings and the installation of windows all around the cabin. Total cabin space is 140 cubic feet, which provides ample room for five passengers or mail freight transport.

General details of the plane as originally built for commercial service and as used on the New York-Berlin flight are:

Span	46 ft. 6 in.
Length	26 ft. 9 in.
Height	8 ft. 9 in. (With landing gear)
Wing chord	6 ft. 7 in.
Weight empty	1,850 lb.
Weight loaded	3,454 lb. Std. 5,400 lb. New York-Berlin
Weight per hp.	17.2 lb. 27 lb. New York-Berlin
High speed	130 m.p.h.
Cruising speed	110 m.p.h.
Landing speed	47 m.p.h.

The Wright J-5C Whirlwind engine employed in the plane has participated in all the honors which fell to the Bellanca plane prior to its latest exploit and, in addition, was the same type engine used by Capt. Charles Lindbergh on his New York-Paris flight.

Chamberlin is credited unofficially with a non-stop flight of approximately 3,905 miles, this being the estimated distance over his course from New York to Eisleben, about 110 miles southwest of Berlin, where he made his first landing after taking off from Roosevelt Field 42 hours before. Capt. Lindbergh covered 3,610 miles on his historic trip from New York to Paris. Chamberlin's average speed on the basis of his estimated mileage and time in the air was about 93 miles per hour, as compared to Lindbergh's 108 miles per hour.

Curtiss Carrier Pigeon.—While most of the activities of the Curtiss Aeroplane and Motor Company are in connection with government contracts, various types of airplanes adapted for commercial purposes have been constructed by this firm. The Carrier Pigeon, which is clearly illustrated in one of the preceding chapters at Fig. 42 is a mail or freight airplane of large capacity.

It is a biplane having an exceedingly deep body which carries half a ton ot mail (40,000 letters) or parcel post or express packages. Using the same power plant, it carries, at a decreased expense and an increased speed, twice the load carried by the DH Air Mail planes.

The wings of the airplane are of wood and steel construction, fabric covered. The upper and the lower wings are so designed that they are interchangeable, no center wing section being required. The wing beams are of solid routed spruce, with no glued joints to deteriorate. The ribs are of Warren truss design, giving a tested strength well over the maximum required in the airplane. The factor of safety of the wing structure averages 25 per cent over that required in the design. Not only have the main structural members of the wings been carefully analyzed for strength but also every detail fitting and bolt. This is also true, of course, of all other parts of the structure. Sidewalk panels of ample size are provided on the wings for use in servicing the machine and in handling the mail.

The tail surfaces have the same general shape and are similar in construction to the wings. All control surfaces are of such a size as to insure adequate control at all speeds. The factor of safety in the tail, owing to the thick tail surfaces, is unusually high, being, in some cases, over three times that required. The rudder, elevators and ailerons are identical, being interchangeable one with the other, thus reducing the number of spares to a

minimum. The right and the left stabilizer are interchangeable, as are the ribs in both the fin and stabilizer.

The fuselage frame and the engine mount are constructed of welded steel tubing, using a Warren truss construction, dispensing with the usual wires which require periodical adjustment. The mail compartment is located on the center of gravity of the airplane, thus insuring proper balance at any mail load. The mail compartment is accessible from the side as well as from the top by means of hinged doors of such size as to admit very bulky packages. Loading and unloading of mail is facilitated to a high degree.

Special attention has been paid to the design of the landing gear and tail skid. The former uses the rubber "doughnut" type of shock absorbing medium employed on the PW8 pursuit planes. The danger of the axle fouling brush, hay, snow, etc., is, of course, reduced to nothing with the axleless landing gear. The wheels are large and the tail skid proper is a large, high tensile steel tube. It is steerable and sprung, to give the easiest possible shock absorbing qualities.

The engine is the Liberty XII with all latest improvements. The gasoline tank, located under the mail compartment and also faired into the fuselage lines, is dropable in flight, an insurance against fire in case of an imminent crash.

The pilot's seat is made especially for use with a parachute and, in addition, is shaped to fit the pilot's body. It is adjustable to accommodate different pilots and arm rests, made adjustable, are installed for the comfort of the pilot. The rudder control is by means of pedals with swiveling foot rests, while the control column can be instantly changed to either stick or wheel control, to suit the convenience of the pilot. The aileron control is of the "differential" type, insuring adequate control even near stalling speed. The ailerons also are so lined that each side is an independent unit.

CHARACTERISTICS

Length, overall	28′-7⅛″
Span, overall	41′-11″
Height, overall	12′-1″
Engine	Liberty 12
Horsepower	400 at 17 r.p.m.
Weight empty	3208 lbs.
Useful load	1856 lbs.
Gross weight	5064 lbs.
High speed (sea level)	128 m.p.h.
Landing speed	51.7 m.p.h.
Service ceiling	15200 ft.
Absolute ceiling	16700 ft.
Range (cruising speed)	590 miles

Curtiss "Falcon" Observation Plane.—The designs of airplanes that have been built by constructors having the facilities of the Curtiss Aeroplane and Motor Company are so numerous that a special treatise could be written on the types developed by that one firm alone as these range from small racing airplanes of about 20 feet spread to large bombers with twin engines having nearly 100 feet span. The Curtiss engineers have designed

all types, ranging from one to three or more sets of planes and with all conceivable arrangements of aerofoils and control surfaces including flying boats, which this company pioneered, float seaplanes with single and double floats and amphibians. Many designs have been made, flown and discarded that the public has never heard of, so it is with considerable hesitancy that the writer picks any one type as being a typical Curtiss design. The "Carrier Pigeon" previously described is a good example of Curtiss commercial design and the "Falcon" observation plane has been selected as a good example of late Service plane construction. This design, which is shown at Fig. 332, was built for the U. S. Air Service and while it is a two-place observation plane, its speed, climb, ceiling and maneuverability could

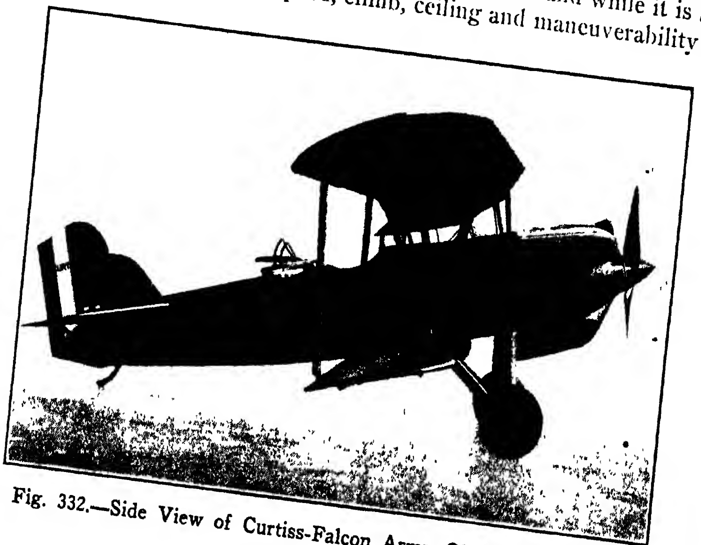


Fig. 332.—Side View of Curtiss-Falcon Army Observation Biplane.

place it in the pursuit class. A considerable part of its light weight is made possible by the use of duralumin tubing in the fuselage. The Falcon was designed to use either Curtiss D12 or V1400 motors, the Liberty 12 or the Packard 1A-1500 for power. R. A. F. wires are used for bracing the biplane wing cellule, the upper wings of which have a pronounced "sweep back." Only one set of interplane struts is used on each side, these being of tubing.

CHARACTERISTICS

	1A-1500	Liberty 12
Length, overall	27′-10″	Same
Span, overall	38′-0″	Same
Height, overall	10′-3″	Same
Engine	Packard 1A-1500	Liberty 12
Horsepower	508 at 2100 r.p.m.	415 at 1760 r.p.m.
Weight empty	2304 lbs.	2477 lbs.
Useful load	1511 lbs.	1578 lbs.
Gross weight	3815 lbs.	4055 lbs.
High speed (sea level)	154 m.p.h.	152 m.p.h.
High speed 10000 ft.	147.4 m.p.h.	136.5 m.p.h.
High speed 20000 ft.	131.6 m.p.h.	93 m.p.h.
Landing speed	63 m.p.h.	63 m.p.h.

Rate of climb (sea level)	1725 ft./min.	1235 ft./min.
Service ceiling	23400 ft.	18700 ft.
Absolute ceiling	24800 ft.	20300 ft.
Endurance (high speed, 15000 ft.)	3½ hours	4 hours

Multi-Motored Airplanes.—The possibility of a forced landing due to engine trouble with a single-motored airplane, if the experience of the United States Airmail can be taken as any criterion is one for every hundred flights. English figures show that in one English transport line that made 3,502 flights of an average of three hours duration, there were 87 forced landings due to engine trouble or one forced landing for every 40 flights. These figures were compiled for airplanes using water-cooled engines and would undoubtedly be less with air-cooled engines because the United States Airmail figures show that 30 per cent of the landings were due to water circulation system troubles and the English figures show that this is not an unreasonable percentage because they arrived at twenty-eight per cent of the forced landings as due to cooling system faults. For this reason, the concensus of opinion of those fitted to judge the requirements of commercial airplanes is that these be fitted with more than one power plant, because the risk of forced landings becomes less as the number of engines increases, providing, of course, that the number of motors does not so greatly reduce aerodynamic efficiency as to partly nullify the advantages obtained. Another requirement to secure practical immunity from forced landings in event of failure of engines, is that the ship can fly with only one of its engines in case of failure of the rest of the power plant. When two motors are employed, the degree of reliability is increased over that of a single-engine ship but not nearly as much as in a three-engine plane.

By considering the law of probabilities, planes with three water-cooled engines having the same reliability of operation as the single-engine plane with one forced landing per 100 flights would have one forced landing for each 535 trips. With air-cooled engines instead of water-cooled, the figure for a single engine ship would become 133 trips and for a multi-motored air-cooled power plant, the percentage would be greatly increased over the figure previously given and has been estimated as one forced landing for each 3,333 trips, which, to say the least, makes a forced landing with a three-engine ship a somewhat remote possibility. Forced landings due to structural defects of the airplane structure are now practically eliminated, but this cannot be said for the airplane power plant, despite its present high state of development, as there still remains the danger of stoppage due to mechanical defects or trouble in ignition and carburetion even if cooling faults are entirely eliminated by use of air-cooled cylinders. Ignition and carburetion systems cause more stoppages than lubrication failures, so some authorities predict that engines which do not require electrical ignition or the conventional carbureting system are a logical development for the future. There is also a danger from fire, which the use of multi-motors certainly does not reduce because explosive fuel or rather one capable of extremely rapid combustion at atmospheric pressures must be used in all engines of the present Otto-cycle form, regardless of the cooling system employed.

Diesel Engines Proposed.—Internal-combustion engines of the Diesel type have been suggested to reduce the risk attendent upon stoppage or fire. The first danger is entirely one of mechanical considerations, the whole solution of which devolves upon the detailed design of the engine with a view to the elimination of all unreliable features. On the other hand, the second danger, that of fire, is of basic origin since it is entirely a problem of fuel. A great deal of experimental work has been carried on both here and abroad in the development of an engine suitable for aircraft which will not require the use of fuels, such as gasoline, with a very low flash point. Heavy oils are very difficult to ignite because they vaporize slowly and even when ignited, burn slowly.

Since there would appear to be little hope of making gasoline non-explosive, the most logical direction in which to turn for the fireproof engine is toward the Diesel principle. As is well known, the fuel used in this type of engine is not explosive, having a very high flash point. It is rendered explosive and made to develop power, through being brought to a very high temperature in the combustion chamber. This heat is obtained by enormous and sudden compression of the vapor in the engine cylinder. It is said that the natives of Borneo use a similar principle to make fire, tinder being placed at the bottom of a wooden tube into which a plunger is rapidly forced with the result that the compressed air becomes so hot that the tinder ignites. While this Diesel principle has distinct possibilities for airplane engines since the Diesel engine is one of the most satisfactory marine engines in use, it has the great disadvantage in that the exceedingly massive cylinders necessary owing to the very high pressures used are almost prohibitive in airplane power plants because of weight. It is understood that, while success with an engine of this type for airplanes is not yet in sight, there is every reason for hope in the near future as reports indicate that Diesel type engines have been made sufficiently light for airship use.

While it is probable that one Liberty engine in a mail plane would consume 25 to 30 per cent less fuel than three 200 horsepower engines, the cost of fuel is given as only about 5 per cent of the cost of operation so the augmented cost of fuel for three engines would be about 1½ per cent which may be considered very cheap insurance.

There are other important points to be considered. The public at present is not air-minded because it is afraid to fly and distrusts the use of the present single- and even twin-engine planes. It does not even risk its mail or express in large volume with such planes. Its main fear is not of flying but of forced landings. Remove the cause of most of the forced landings by using three-engine air-cooled planes and the psychological reaction will be apparent in greatly increasing number of commercial applications. The experience of those who have operated air lines for commercial transport is that two engines is not enough and that more than three engines is unnecessary except in the case of very large airplanes, because when more than three engines are used, structural and aerodynamical problems are introduced that demand very careful consideration. It is not difficult to install three engines. One is placed at the nose of the fuselage, which one must have with even a twin-motored ship, the other two are carried outboard in the same manner as in the twin-motor types. Use four or five

motors and their placing becomes more difficult. If two pairs of motors are mounted outboard, one must be placed back of the other to keep resistance down but air screw efficiency suffers because one screw must work in the slipstream of the other which the writer has previously shown to be undesirable. If four motors are mounted outboard as separate power plants then structural problems are introduced that are not easy of solution. The three-motored airplane is therefore the most popular and practical multi-engine type because it is the most reliable construction that can be secured with minimum sacrifice of efficiency.

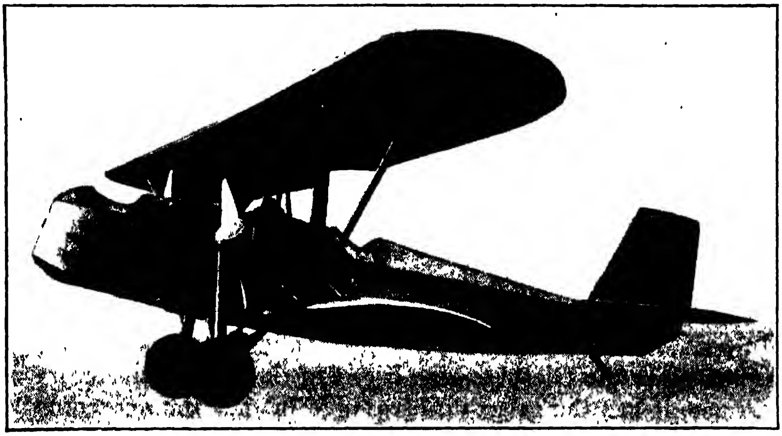


Fig. 333.—Heinkel Twin Motor Biplane Equipped with Wright "Whirlwind" Engines. Note Streamlining of Engines and Propeller Hub.

Heinkel Twin-Motor Biplane.—The new Heinkel Model HD-20, built at Warnemunde, Germany, by the Heinkel Flugzeugwerke, and powered with two Wright "Whirlwind" J-4-B engines, has proved a conspicuous success. It is a sesqui-plane, convertible for use over either land or water. Either one of the two "Whirlwind" engines can be removed in a few minutes, complete with its oil tank, by disconnecting four bolts. The framework of the machine is welded steel tubing and is covered with doped fabric. The neat and trim appearance of the whole can readily be judged from the photograph. The beautifully streamlined cowling for the engines and oil tanks, the absence of wires, and the balanced elevator and rudder, should be noted especially.

The useful load capacity is about 1,400 pounds, and the cruising range three hours, which is nothing remarkable for a commercial plane with four hundred horsepower, but it is reported that the climb and the maneuverability are excellent, and that the machine can be stunted like a sport plane. A feature which makes this a particularly good photographic plane, is the fact that the camera is mounted in the front cockpit, well ahead of the engines, obviating any possibility of getting oil on the lens. The front cockpit location in a twin-engine plane also gives the camera an unusually wide field, free of all obstructions.

Although outstanding in its fine qualities for photographic work, a plane

of this type has very interesting possibilities for observation and training. Especially for night observation, the use of two standard, reliable air-cooled engines, plus the ability to fly with moderate load on one engine alone, gives this type distinct advantages over any other now in use. The observer's field of vision is remarkably good. As a small bomber, such a machine would materially reduce the cost of training personnel, and still have the advantage of training them in a modern high performance ship, with up-to-date equipment, including air-cooled radial engines.

The Heinkel HD-20 should also be unusually safe. Unless it is overloaded, the machine can be kept in the air with one engine only, and since the vertical fin is adjustable in flight, the pilot can easily maintain control while flying with only one engine. The wing loading is very light, the take-off is quick and the landing speed low. The general characteristics are as follows:

Span, upper	12.8 meters	42 ft.
Span, lower	8.8 meters	28 ft. 10 in.
Length overall	9.45 meters	31 ft.
Height overall	3.02 meters	9 ft. 11 in.
Total wing area	39.8 sq. meters	428 sq. ft.
Weight empty	1300 kg.	2860 lbs.
Full load weight	1950 kg.	4290 lbs.
Maximum speed	190 km. per hour	118 m.p.h.
Landing speed	85 km. per hour	53 m.p.h.
Climb to 1000 meters	3½ minutes to 3280 ft.	
Climb to 2000 meters	7½ minutes to 6560 ft.	
Climb to 3000 meters	13 minutes to 9840 ft.	
Climb to 5000 meters	35 minutes to 16,400 ft.	
Endurance	3 hours	
Range	570 km.	355 miles
Lb./sq. ft.	10	
Lb./hp.	10.7	

Caproni CA73 Bomber.—The Italian constructor, Caproni has built very large bombing planes and examples of his extremely large biplanes and triplanes used during the late War have been previously illustrated in Chapter 7 at Figs. 111 and 112. A new and smaller plane is shown at Fig. 334 to show an unusual method of two-motor installation. The engines are installed in an individual nacelle above the body in the interplane gap as is often done in flying boat practice. The wing arrangement is somewhat novel, the upper wing being considerably smaller than the lower wing as shown at Fig. 334 A. Both wings are of thick section, the span of the lower one being considerably larger than that of the upper, as is also the chord of the lower wing. This arrangement necessitates a very marked inward slope (upwards) of the outer interplane struts, this fact undoubtedly being largely responsible for the fact that, in spite, of the comparatively large span of the machine, there is only one interplane bay. The inward sloping struts undoubtedly provide a distinct lateral stiffening component in the wing structure. The only other interplane bracing struts are a single pair of vertical struts arranged in conjunction with the undercarriage structure on each side of the fuselage, and a sloping Vee arrangement between which the engine nacelle is mounted. The lower wing is

attached to the top longeron of the fuselage. The top wing is flat while a pronounced dihedral is put into the lower wing. Ailerons are fitted to the lower wing only and these are balanced and of large size. The engine nacelle is mounted above the fuselage on a double "M" arrangement of struts which undoubtedly provide considerable rigidity, especially as these struts are all quite short in length. The engines are radials and each apex of the "M" is arranged to support the actual engine bearer of each engine.

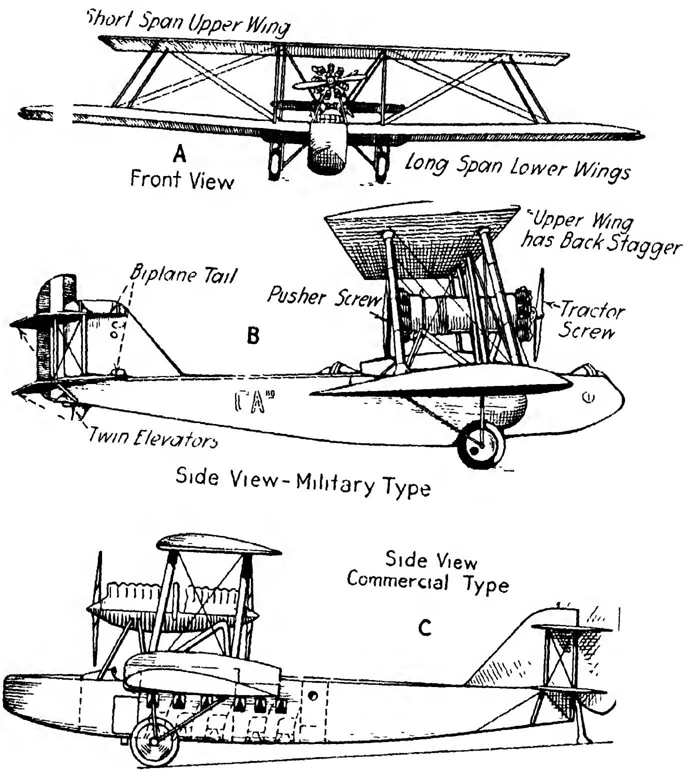


Fig. 334.—Drawings Showing Construction of Caproni CA 73 Bomber with Tandem Engine Installation. A—Front View Showing Short Upper Plane. B—Side View Showing Low Placing of Fuselage. Note Biplane Empennage. C—Side View Showing Plane Designed with Passenger Carrying Cabin.

The undercarriage is simple and consists of two parts, each individual and carrying a wheel on one side of the fuselage. Each part consists of a normal double Vee structure braced laterally by means of a single sloping strut extending to the top fuselage longeron. Each Vee carries its own axle for its individual wheel. The tailplane is of normal form but consists of a biplane formation with the upper surface supported at a point near the top of the vertical fin. A single pair of interplane struts brace the

tail structure just as in a small wing structure. Elevator flaps are fitted to each surface of the stabilizer group, these being split to allow for the movement of the rudder which is of normal balanced type.

The engines are Jupiter air-cooled radials of 420 horsepower each, the forward engine driving a two-blade propeller while the after engine drives a four-blade propeller. Lorraine Dietrich water-cooled engines of 450 horsepower each have also been fitted and such an arrangement is shown at Fig. 334 C.

The general dimensions of the Caproni CA.73 are as follows:

Length	49.5 ft.
Span	82.0 ft.
Height	18.5 ft.
Weight Empty	7055 lb.
Load which can be carried	4409 lb.
Total loaded weight	11464 lb.
Total which can be carried on one engine	2645 lb.
Load per sq. ft. wing surface	7 lb.
Load per horsepower	14 lb.

The plane carries a pilot and observer with a forward and a rear gunner, each of the latter two having an individual cockpit fitted with the usual form of gun ring mounting. The machine is said to be very maneuverable, especially in view of its size. Being fitted with tandem engines, it is possible to fly with either engine stopped with the minimum of difficulty in control and the load capable of being carried on one engine (2,645 pounds) is quite appreciable. The general performance of the machine is as follows:

Maximum speed	115-118 m.p.h.
Climb to:	
1000 meters (3280 ft.)	5 min. 20 sec.
2000 meters (6560 ft.)	12 min. 30 sec.
3000 meters (9840 ft.)	21 min.
4000 meters (13120 ft.)	34 min.

The Caproni Company has drawn up plans whereby the CA.73 can be transformed from a bombing plane into a commercial passenger machine. A cabin would be provided as shown at Fig. 334 C for ten passengers, seats being arranged in two rows in the cabin with an aisle between. Entrance would be through a door placed just under the leading edge of the lower wing and it is estimated that the plane would be very suitable for such an adaptation.

The C.P.A.1 Two-Motor Bomber.—The makers of this unusual long range bombing monoplane, the C. P. A. Company are a French firm. The airplane is a braced wing monoplane powered with two 500 horsepower water-cooled Hispano-Suiza engines, the drawings at Fig. 335 showing clearly the method of power plant installation and also the manner of bracing so a strong structure is obtained, the wing bracing extending from the engine nacelles which are mounted directly over the dual wheel landing gear struts. The wings are of standard wood box spar construction, with ribs also of wood and closely spaced. The struts, which brace the wings and form the engine mounts, are made of wood.

Trailing edge wing flaps are used, extending the entire length of the wing span. The outer portions of this flap are divided from the inner portions on each side and are capable of individual operation as ailerons for lateral control. The wings have no dihedral but have a considerable sweep back in plan form. The fuselage is of standard wood and wire construction with the pilot's cockpit arranged behind the wing, while the observer's cabin extends back from the gun ring in the nose for some fifteen feet. The cabin has windows for observation and bomb sighting. There is also a

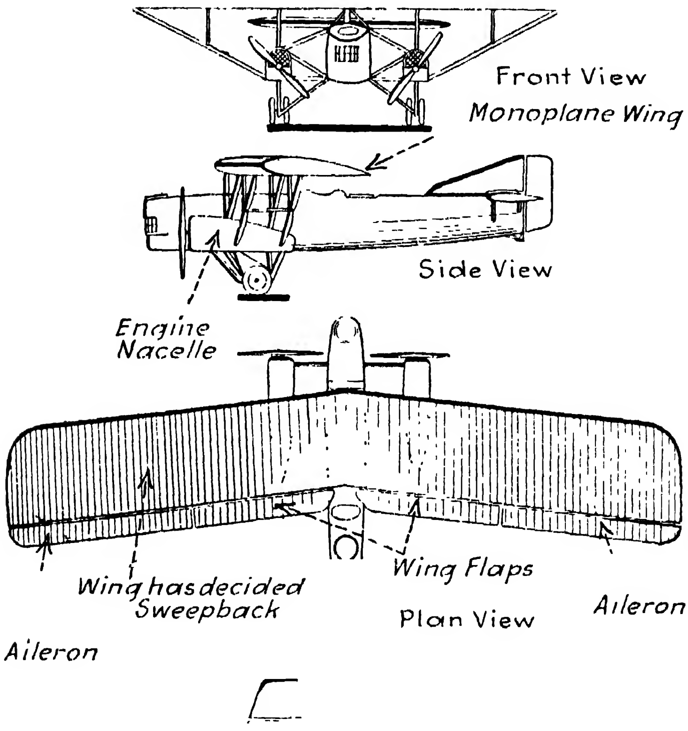


Fig. 335.—Outline Drawings of the C. P. A. 1 Twin Engine Monoplane Bomber.

bomb rack for forty 22 pound bombs or for ten 110 pound bombs. A trap door is constructed in the floor of the fuselage, in the after portion, in order that a hasty exit by parachute may be made by the occupants of the plane.

The gasoline tanks are arranged in the wings above the engines and can be emptied in flight by a knife, actuated by a spring, which rips out the bottoms of the tanks. The two tanks can be interconnected in case of necessity. Dual control is provided for the pilot and rear machine gunner, each having controls which can be disconnected from either seat. The armament of the plane consists of six machine guns, two being placed in the nose of the fuselage, two in the gunners' cockpit, just back of the pilot's cockpit, and two which can be fired through the bottom of the fuselage to the rear and downwards.

The general characteristics of the plane are as follows:

Span	74 ft. 10 in.
Chord	12 ft. 3 in.
Length	48 ft. 10 in.
Area	903 sq. ft.
Weight empty	6,600 lb.
Weight loaded	10,900 lb.
Weight per sq. ft. of wing area	12 lb.

Estimated performance:

High speed	130 m.p.h.
Landing speed	55 m.p.h.
Ceiling	24,600 ft.

Performance on one engine:

High speed	75 m.p.h.
Ceiling	7,500 ft.

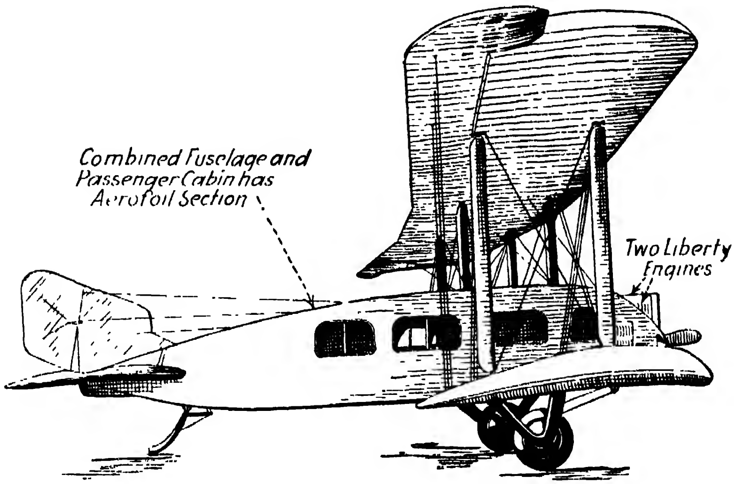


Fig. 336.—Drawing Showing Side View of Remington-Burnelli Biplane Having Fuselage of Aerofoil Section so it Contributes Useful Lift while in Flight, Acting as a Short Span Thick, High Lift Wing. Cabin is Very Spacious.

Remington-Burnelli Airliner.—This large biplane twin-motored airliner is a very unusual design because that while two engines are employed, these are mounted side by side in the fuselage itself. This machine has made numerous flights around Mineola, Long Island where it was built. The unusual engine mounting is rendered possible by the fact that the fuselage is extremely wide and the Liberty engines are installed in the two front corners of the nose. The fuselage is further interesting because of its unusual shape, a side elevation: it being designed to form the contour of an airfoil as far as possible, is shown at Fig. 336. It undoubtedly contributes to a certain extent to the total lift of the plane as a result of this feature. The size of the fuselage allows considerable cargo or passenger space, the cabin measuring 14 feet by 16 feet by 6 feet. The construction

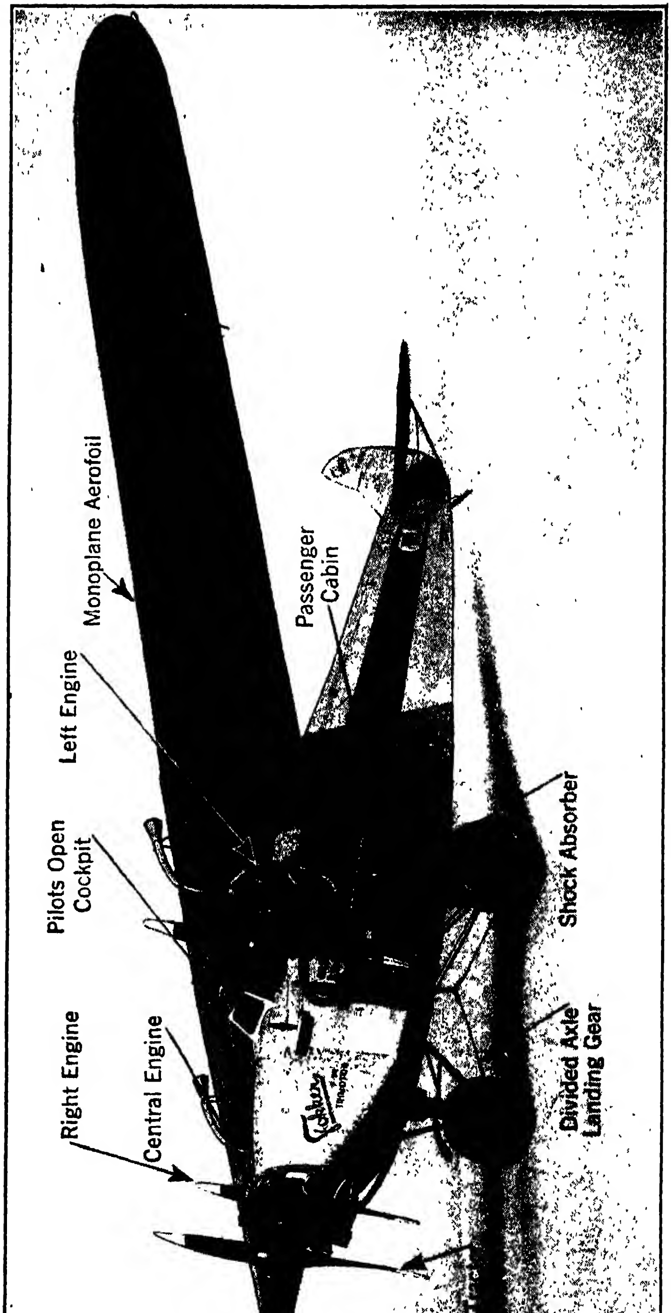


Fig. 337.—One of the Fokker F VII Tri-motor Cabin Monoplanes Used During the Sesquicentennial Exposition by the Philadelphia Rapid Transit Air Service for Passenger Carrying Between Philadelphia and Washington and Norfolk, Va.

of the fuselage is of duralumin, riveted channel section struts being employed together with a corrugated sheet covering which contributes considerably to the structural strength.

The wing construction is original, consisting of box type duralumin girders with lattice webs. The compression struts are spaced approximately 6 feet apart and conform to the wing contour. Between the compression struts, and fastened to them, are duralumin U section members, spaced 2 feet apart running laterally. They are used to take the covering load and do away with the conventional rib construction. The covering of the wing is of light gauge duralumin, 1¼ inch pitch and ⅜ inch deep, formed to the wing contour and riveted to the wing beams. The location of the wing beams from the leading edge is 19 per cent of the cord for the front beams and 69 per cent for rear beams. The length of the center section is 14 feet, that of the inner bay 18 feet and that of the cantilever panels 14 feet.

SPECIFICATIONS

Following are the general details of the machine:

Wing span	78 ft.
Wing chord	10 ft. 6 in.
Gap	11 ft. 4 in.
Wing area	1517 sq. ft.
Areas of tail surfaces	
Horizontal stabilizers	44 sq. ft.
Elevator	74 sq. ft.
Vertical fin	33 sq. ft.
Rudder	36 sq. ft.
Weight, empty	9,450 lb.
Cargo, passengers and crew	4,000 lb.
Fuel and oil	2,150 lb.
Total loaded weight	15,600 lb.

Fokker Tri-Motor F VII.—This is a commercial transport airplane that when used for passenger traffic will carry 2 pilots, 10 passengers, 540 pounds of baggage for 500 miles at a speed of 100 miles per hour. By reducing the number of passengers to 8 and the baggage load to 380 pounds the range can be increased to 700 miles or 7 hours flight. For freight, express or mail, 1,820 pounds of pay-load may be carried in a 500 cubic feet capacity cabin, with two pilots and sufficient fuel and oil for 700 miles. Reducing the range to 5 hours flight increases the pay-load to 2,340 pounds. An airplane of this type was the first to fly over the North Pole and was the first tri-motored airplane to cross the Atlantic in one hop. Another accomplishment was the flight from California to the Hawaiian Islands. One of these machines which received actual application in air transit is shown at Fig. 337, and was used by the P. R. T. Air Service, flying between Philadelphia and Washington. This type of plane is also used on Boston to New York Airline and has been widely used abroad.

The high importance of perfect flying qualities in commercial aircraft deserves far more positive recognition than it has generally received in the past. Under normal conditions and with engines running perfectly the absence or presence of good flying qualities is not apparent, hence very

often neglected unless the test pilot is specially trained to investigate and report on such matters during the initial flight tests. When bad weather is encountered, engine failure occurs, or a landing has to be made as slowly as possible and in a difficult place, the flying qualities of the ship determine the whole issue. In fact, the very prevalent lack of appreciation of the real nature of perfect flying qualities is undoubtedly the reason why so many accidents, even to experienced pilots, are put down as either "unexplainable" or "unavoidable," while they are really the result of unsafe flying qualities when flying at low altitudes and low speeds. On the elimination of these dangers Mr. Fokker has concentrated all his experience and skill as a designer and a pilot, personally making every test, with the well known "non-stalling" and "non-spinning" qualities of Fokker aircraft as a result.

In its general construction and use of materials, the Fokker Tri-motor F VII follows closely the highly successful features of the long line of Fokker commercial craft which have preceded it. As an aerodynamical design, the thick winged monoplane, with the wings placed high up, on the fuselage, originated in the Fokker F II of 1920, has never been equaled by any other type of design in efficiency as a load carrier for a minimum expenditure of power. Similarly, the inherent advantages of the steel tube fuselage structure, combined with the all wood, veneer planked wing, used in all Fokker commercial aircraft, are so firmly established that their adoption in the Tri-motor is a matter of course.

As already described, the wings embody the thoroughly proven Fokker all wood, veneer covered construction. For ten years now this form of construction has been standard on all Fokker monoplanes and has proven so satisfactory in service that it is this part of the ship that has undergone the least change during this long period. The cost and time expended on repairs and maintenance work on wings of this type have been conclusively proven to be lower than any other type of construction known at the present time. Repairs can be made anywhere by any carpenter; recovering has never been found necessary, except locally in case of accidental damage, and normal maintenance year after year is practically reduced to occasional varnishing. A most important feature of the wooden wing is also its flexibility, which permits deflection under overload without permanent deformation; no rivets or connections can be strained, as the wings form one continuous, unbroken structure. The wing spars are built up of box section, with heavy laminated spruce upper and lower flanges and birch veneer plywood walls, suitably blocked where necessary. The ribs are built up of birch plywood with spruce cap strips and stiffeners and the entire structure is both covered and solidly bound by the complete birch plywood covering, which is glued, nailed and screwed on. The result is a wing which is not only very light in weight but which will stand regular use under all weather conditions, with a minimum of deterioration.

Fokker Power Plant Installation.—The three Wright "Whirlwind" air-cooled radial engines of 200 horsepower contribute greatly to the commercial utility of the Fokker Tri-motor. Large numbers of these engines are in use in the United States Navy and in civilian aircraft of many kinds; they have an excellent reputation for reliability and wearing qualities. The inherent simplicity of the radial engine and the accessibility of its parts re-

sult in low maintenance costs and a minimum of hours out of service for overhauls and repairs. Two hundred hours service without overhaul is a normal performance for these engines. The average fuel-consumption on the Fokker Tri-motor in normal commercial operation is only about 39 gallons per hour, for the 3 engines. Oil consumption averages below 9 quarts per hour; several brands of heavy oil, commercially easily obtainable, are suitable. The center engine is bolted to the nose of the fuselage, while the two side engines are mounted on well designed tubular steel nacelles suspended below the wing and attached thereto by three bolts. This location of the engines, an original Fokker design of great value, avoids interference with the aerodynamic qualities of the wing, an interference which has proven to be of the greatest detriment to the qualities of the entire ship in designs where the engines have been located in, against or immediately on top of the leading edge of the wing.

The design of the exhaust manifolds is also the result of much experience and testing. They consist of a system of short lengths of flexible metallic tubing clamped to rigid joints. Replacements are, therefore, very cheap and quick to make. All possibility of straining the cylinders is avoided and individual cylinders can be removed quickly without detaching the manifold.

Strainers are placed in the line at each engine, in addition to screens over the tank outlets. Gravity feed only is used, avoiding all complications in the way of pumps and their accessories. In the standard installation, two gasoline tanks, of 95 gallons each, are placed in the center section of the wings, between the enormous wing spars; this is undoubtedly the most protected position conceivable on any aircraft. Provision is made in the wing structure for installation of a third tank when desired. Each tank feeds the fuel system independently, through a shut-off cock. These cocks form part of a manifold installation on which the three individual feeds to the engines are also each controlled by separate cocks. On top of this manifold, which is mounted right next to the two pilot's seats and in full view, boiler type glass tube stand pipe level gauges are provided for each tank, the only absolutely reliable and positive type of gauge known. They are calibrated and marked both for standing and flying positions of the ship and are provided with shut-off cocks, in case of breakage; this is unlikely as the gauges are protected by a transparent pyralin box. Each engine mount carries its own oil tank, the total oil capacity being 21 gallons.

General Fokker Features.—The pilot's cockpit is roomy and conveniently arranged. A three piece glass windshield gives such protection that goggles are not needed under normal conditions. The cockpit is entered from the cabin through a large door fitted with a window. The passenger cabin is 10 feet long, 5 feet wide and 5 feet 10 inches high. Eight comfortable wicker arm chairs are provided. Glass windows run the entire length of the cabin and may be opened for ventilation. Provision is made for heating the cabin. The floor is covered with carpet or linoleum. A completely equipped wash room is located at the rear of the cabin. The main access door, in the side of the fuselage is entered by way of one step. directly from the ground. This door is 4 feet 5 inches high by 2 feet 6 inches

wide. A separate baggage compartment is located at the rear of the main cabin.

Complete dual control, of the wheel and column type is fitted. The stabilizer is adjustable in flight by a worm gear, operated by a crank and shaft from the pilot's seat. Elevators and rudder are balanced. Ailerons are wood construction, veneer covered as the wings are. The landing gear is of wide wheel track, the 44 inch by 10 inch tired wheels being spaced 15 feet apart. Each half of the landing gear consists of an axle and radius rod hinged to the lower longeron of the fuselage, and a vertical shock absorbing strut abutting at the top directly on the side engine nacelle. In landing, the entire weight of the side engines is thus borne directly by the landing gear instead of through the wing structure. The shock absorbing strut itself is the product of a great deal of experience; especially in passenger traffic, perfect shock absorption, not only in landing but particularly in taxiing, is of the greatest influence on the comfort of the passengers. The shock absorbing elements themselves are horizontally suspended individual rubber rings which allow a very long stroke, both in taxiing and landing. The action is extremely soft and causes no tendency to bounce. The quickly and individually replaceable rings are a valuable maintenance feature. Brakes of special design are installed, by means of which the roll after landing can be reduced to a very short distance by the pilot or his assistant in case of an emergency landing in a very small field. The mud guards are attached to the vertical struts, so that they do not have to be touched when removing wheels.

SPECIFICATION

Fokker Type F VII Commercial Airplane Fitted With Three 200 H. P. Wright "Whirlwind" Engines

Dimensions

Span	63′4″
Length	49′2″
Height	12′9″
Track of Landing Gear	15′

Disposable Load

Alternative Dispositions:

Fuel and Oil (5 hours)	1,300 lbs.	
Crew (2)	360 lbs.	
Passengers (10)	1,800 lbs.	Pay-load
Baggage	540 lbs.	2,340 lbs.
Total	4,000 lbs.	

or

Fuel and Oil (7 hours)	1,820 lbs.	
Crew (2)	360 lbs.	
Passengers (8)	1,440 lbs.	Pay-load
Baggage	380 lbs.	1,820 lbs.
Total	4,000 lbs.	

Performance

Climb—Official U. S. Government Tests

Military Disposable Load
2,975 lbs.

Rate of climb at ground level .... 860 ft./min.
5,000 ft. .... 6.9 min.
10,000 ft. .... 17.5 min.
15,000 ft. .... 42.1 min.
Ceiling .... 16,950 ft.

On two engines only
Rate of climb at ground level .... 530 ft./min.
Ceiling .... 11,000 ft.

Commercial Disposable Load
4,000 lbs.

Rate of climb at ground level .... 720 ft./min.
5,000 ft. .... 8.6 min.
10,000 ft. .... 24.2 min.
Ceiling .... 13,950 ft.

On two engines only:
Rate of climb at ground level .... 343 ft./min.
Ceiling .... 7,000 ft.

Speed—Manufacturers' Tests

High speed at ground level .... 122 m.p.h.
Average cruising speed .... 100 m.p.h.

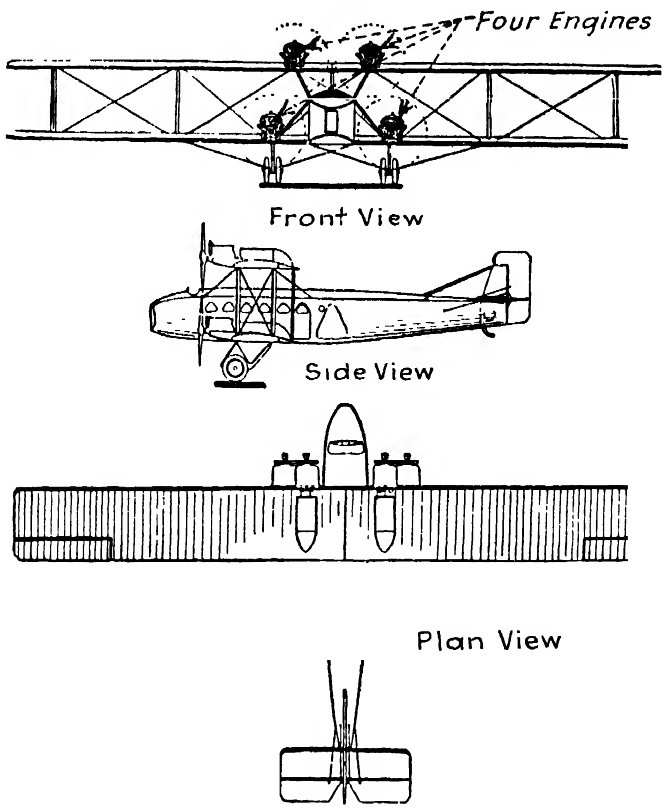


Fig. 338A.—Bleriot Four Engine Airliner with Engines Mounted so There will be no Interference between Propeller Slipstreams.

Bleriot Four Engine Airliner.—This large biplane is built by the Bleriot Company, the founder of which was the first man to cross the English Channel by airplane, which feat he accomplished with a small monoplane of his own design so long ago that it is now ancient history in aviation progress. The machine shown at Fig. 338 A carries 17 passengers besides the pilot and navigator-mechanic and was built for use in the Paris-London service. The following details were given in Aviation.

The wings of the Bleriot 155 are of normal biplane structure with a total wing area of 1,444 square feet. The span is of 85 feet 3 inches, while the chord and the gap are each 8 feet 10 inches. The upper and lower wings are absolutely identical, with neither sweep-back, dihedral nor stagger. They are connected by eight interchangeable struts made of light metal tubing. The front and rear wing beams are of the same depth and carry the same load making it possible to use identical wing fittings and cables.

The wings are constructed entirely of wood with the exception of the braces connecting the engines, the landing gear and certain highly stressed parts of the fuselage, which are made of steel, thus insuring absolute rigidity. There are four unbalanced ailerons. The fuselage is arranged to seat 17 passengers in a cabin 15 feet in length. It is lighted by twelve portholes which provide the passengers an excellent view, both below and to the sides. Ventilation is obtained by four air inlets which can be regulated. Besides the entrance door, which is set on one side of the fuselage, the cabin also has an emergency exit towards the front, and one in the roof.

The horizontal stabilizer consists of a fixed portion, the angle of which can be regulated in flight by means of a wheel operated by the pilot, and the elevators, which are unbalanced. The fixed vertical fin is tri-angular in shape and the rudder is unbalanced.

The four engines are set on the leading edges of the wings, on either side of the fuselage, two on the upper wings and two on the lower wings. The slipstreams of the propellers do not interfere with each other in any way but it would seem that there might be serious trouble if one propeller broke, since it would be likely to injure the other propellers, as well as the pilot and mechanic. Four 230 horsepower Renault engines are used turning tractor propellers of 8 feet 10 inch diameter. The cooling is done by a honey comb type radiator, triangular in formation and attached in front and above the engine. The starting of the engines is done by a compressed air starter built by the Sociètè Blèriot-Aeronautique. The pilot can control the four starters while in flight, either together or individually.

The landing gear is placed directly under the two groups of engines; each one consists of two wheels braced by steel tubing in the form of an N. Y. Lateral bracing is obtained by four wire cables, two in front of the wheels and two behind. These cables are attached on one side, to the longerons of the lower wings at the inside wing struts, and to the fuselage on the other side. The shock absorbing is done by Sandows bands fastened around the axle and around the steel tubing. The tail skid consists of a steel tube, hinged at about two-thirds of its length and strung on elastic cord with a steel skate on the rear end.

GENERAL CHARACTERISTICS

The general dimensions of the airplane are given in the following table:

Span	85 ft. 3 in.
Length	48 ft. 4 in.
Height	16 ft. 6 in.
Chord	8 ft. 10 in.
Gap	8 ft. 10 in.
Weight empty, with water and wireless apparatus	8,030 lb.
Weight of fuel	1,760 lb.
Weight of crew	352 lb.
Weight of instruments	88 lb.
Weight of usual load	3,740 lb.
Total weight	13,970 lb.
Weight per sq. ft.	9.4 lb.
Weight per hp.	15 lb.

Performance

Speed at ground level	105 m.p.h.
Cruising speed	90 m.p.h.
Altitude reached in less than 60 minutes	13,300 ft.
Cruising radius	300 mi.

Latécoère Four-Engine Bombing Plane.—Another large French biplane is shown at Fig. 338 B and it is designed to carry bombs for long distances. This biplane shows an arrangement of four engines that is criticized by some aeronautical engineers because the rear engines, which are placed in line with the front ones, must turn their propellers in disturbed air because they operate in the slipstream of the front tractor screws with some loss of efficiency. This plane was also described in a current issue of Aviation.

The plane, which this company built, was originally equipped with four 265 horsepower Salmson engines but the recent model, which is now undergoing tests at Villacoublay, is fitted with four French Jupiter radial air-cooled engines which develop 400 horsepower each. No official flight performance figures have been issued, but the plane has several features which make it of interest. Throughout the design there has been an attempt to make the plane proof against machine gun fire and shell fragments. The result has been sought, not by providing protective armour but by a design whereby the destruction of one member would not cause the collapse of the entire plane. There are, for example, seven spars in the wing and the fuselage is constructed without longerons so that either part could be hit many times without seriously injuring the structure. The defensive armament of the plane consists of one machine gun group in the nose, one projecting from the center of the upper wing and one from a sort of a spur which projects from the center of the upper wing and one from a sórt of a spur which projects from the lower part of the fuselage, just behind the trailing edge of the lower wing. This provides the plane with no blind sports except the area directly behind the tail surfaces. The armament is such that a squadron of these planes could, if attacked by pursuit planes, put up a veritable barrage of machine gun fire. The pilot and observer are protected by armour and enthusiasts for this class of plane claim it could not be brought down, except by an explosive shell of considerable calibre.

The L.A.T.6, as the plane is officially known, has a wing area of 1,291 square feet. The upper wing has a span of 90 feet 8 inches and a chord of 11feet 6 inches. The lower wing is much smaller, having a span of only 67 feet 8 inches. The fuselage extends to the upper wing, eliminating center section struts and giving a very spacious cabin. The wings can be de-mounted in sections for shipment on a French freight car. They are rectangular in form, with a slight dihedral and a very decided sweep back. There are four ailerons, those on the upper wing being balanced. The wing frames are entirely made of metal. The upper wing has nine spars

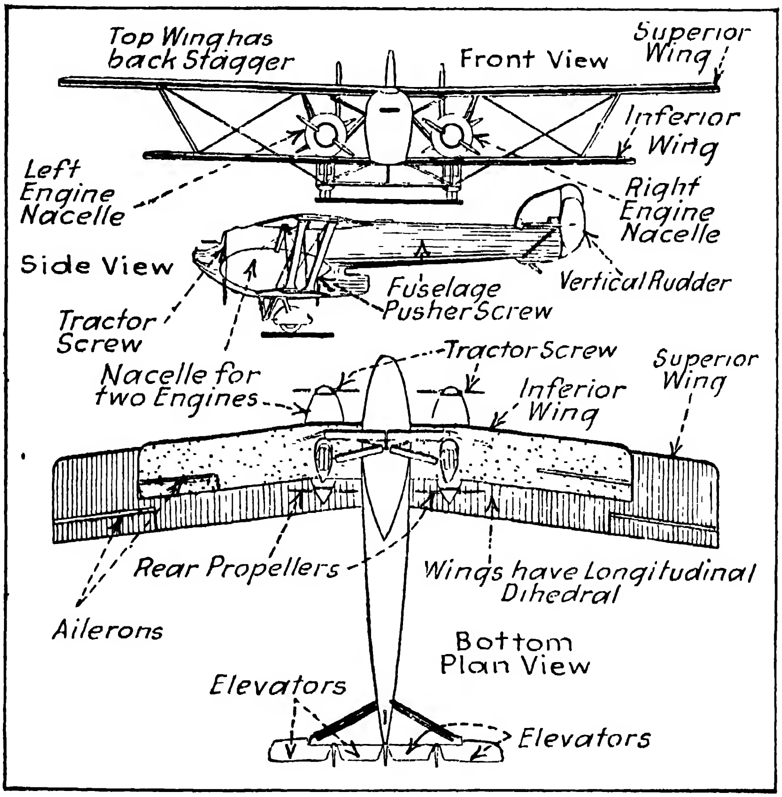


Fig. 338B.—Latecoere Four Engine Biplane has Tandem Engines Mounted in Nacelles Carried between the Wings, the Rear Screws Working in the Slipstream of the Front Ones.

made of reinforced sheet metal, while the lower wing has seven. The cross bracing is at intervals of about six feet and consists of metal tubing. The covering of the wings is also of metal and adds to the structural strength. In static test, the structure withstood a load of 30 tons, indicating a safety factor of 7.5.

The fuselage consists of a metal framework also covered with a metal covering. The fuselage contains a large cockpit for the pilot and observer, protected gasoline tanks which can be emptied in flight, radio cabin and a camera and moving picture installation. The machine gunners, it is notice-

able, are allowed ample room. The tail control surfaces consist of a narrow balanced elevator and three balanced rudders.

The two pairs of engines in tandem are arranged on the lower wing. Each unit containing its own copper lubricating oil tanks and aluminum gasoline tanks. The engine instruments are attached to the engine nacelles in such a way as to be visible from the pilot's seat.

The undercarriage groups are placed under the engine mountings. Each group consists of double tire wheels with streamlined fairing. A rather complicated system of bracing is used to maintain the wheels in position but the structure looks rugged and accessible.

GENERAL CHARACTERISTICS

The general characteristics of the plane, equipped with Salmson 265 hp. engines, are as follow:

Span	90ft. 8 in.
Length	51 ft. 7 in.
Height	14 ft. 1 in.
Area	1291 sq. ft.
Weight empty	9020 lb.
Fuel	3454 lb.
Useful load	1584 lb.
Weight per sq. ft	10.8 lb.
Weight per hp	13.2 lb.
Speed	122 m.p.h.
Ceiling	16,728 ft.

QUESTIONS FOR REVIEW

1. Describe construction of frame of rigid airship of the Zeppelin type.
2. Describe construction and give principal dimensions of typical U. S. Army non-rigid dirigible.
3. What are the main requirements of airplanes for civilian flying?
4. What is the span of the Buhl-Verville biplane and what type landing gear does it use?
5. Outline main features of Fokker Universal airplane.
6. What is the passenger capacity and flying range of a Fokker tri-motor airplane?
7. Describe some distinctive features of the Wright-Bellanca monoplane.
8. What is the possibility of a forced landing with tri-motored airplanes?
9. How are four motors installed in airplanes?
10. How is the Fokker monoplane wing constructed?

CHAPTER XVI

SEAPLANES, FLYING BOATS, AMPHIBIANS AND OTHER AIRCRAFT

Seaplanes and Flying Boats—Metal Hulls and Floats—Curtiss Navy Racer—Advantages of Seaplanes—Float Design and Surface Maneuvering—Features of Future Commercial Flying Boats—Navy PN Series—Characteristics and Equipment of Navy P.N.7—Development of the PN-10 Boat-Seaplane—Boeing P.B.1 Boat-Seaplane—Requirements of Navy Seaplanes—Where Progress is Being Made—Giant Flying Boats—Superboats by Junkers, Rumpler and Ricci Brothers—Amphibian Planes—Disadvantages of Old Amphibious Designs—Loening Amphibian has Excellent Performance—Interesting Structural Details—Table XXII, Characteristics of Various Amphibian Planes—The Autogiro Rotating Wing Airplane—Principles of Autogiro—Helicopter Principles—Many Problems to be Solved—Landing in Event of Engine Failure—Parachutes, Types and Use—Requirements of Parachute Equipment—Approved Types of Parachutes—Control of Parachutes—Maintenance and Use of Parachutes—Parachute Lands Airplane.

Seaplanes and Flying Boats.—A number of airplanes are designed so they can be fitted with pontoons or floats instead of wheeled landing gears which will enable them to alight on water and take-off from that same medium. There are distinctive types using a central hull of boat form which are really flying boats, this class having been developed to a high point of efficiency by the U. S. Navy. The greatest improvement to be made in recent years is in the construction of the floats or hulls which are now often made of metal instead of wood. This not only saves in dry weight but one of the weaknesses of the wood float, that of water soakage with consequent weight increase, is entirely eliminated.

Metal Hulls and Floats.—By using metal instead of wood it has been possible to show a saving of 500 pounds in a PN8 Navy Seaplane. It is said that soakage is a factor that must be considered as it is one of no mean importance. Navy experience is that it may reach values in excess of 10 per cent of the normal flying load. Such metal floats that have been built are of duralumin which is covered with a protective coating to prevent corrosion in salt water. The saving of weight is of material importance even in small floats as an N9 float design of metal weighed but 227 pounds as compared to the same of wood, dry, that weighed 293 pounds and 340 pounds including soakage. Naval development of metal floats dates back to 1913 so various very practical constructions have now been evolved.

A seaplane of the central float type is shown at Fig. 339 B, this being a Curtiss Lark. As will be evident, wing tip floats are necessary to prevent the wings dropping down into the water. Another single float type is shown at Fig. 339 A, this showing a Boeing training type. When twin-pontoon floats are used, the wing tip floats are usually dispensed with. The various forms of hulls and floats are designed from data obtained by towing basin experiments. Floats must be proportioned so that at zero

speed or when at rest, the displacement will carry the weight. At the same time they must be of such form as will plane readily and leave the surface of the water with minimum suction drag when proper flying speed is reached.

Curtiss Navy Racer.—A typical twin pontoon seaplane intended for racing is shown at Fig. 340. The Curtiss racer is really a very small machine, having a wing span of only 22 feet. The lower wing is slightly shorter than the upper wing, its span being 20 feet. The overall length from propeller hub to tail, not including the pontoons which project forward considerably, is 20 feet. The area of wings is a total of 144 square feet, most of which consists of wing radiator surface. The total weight of the seaplane is 2,738.4 pounds.

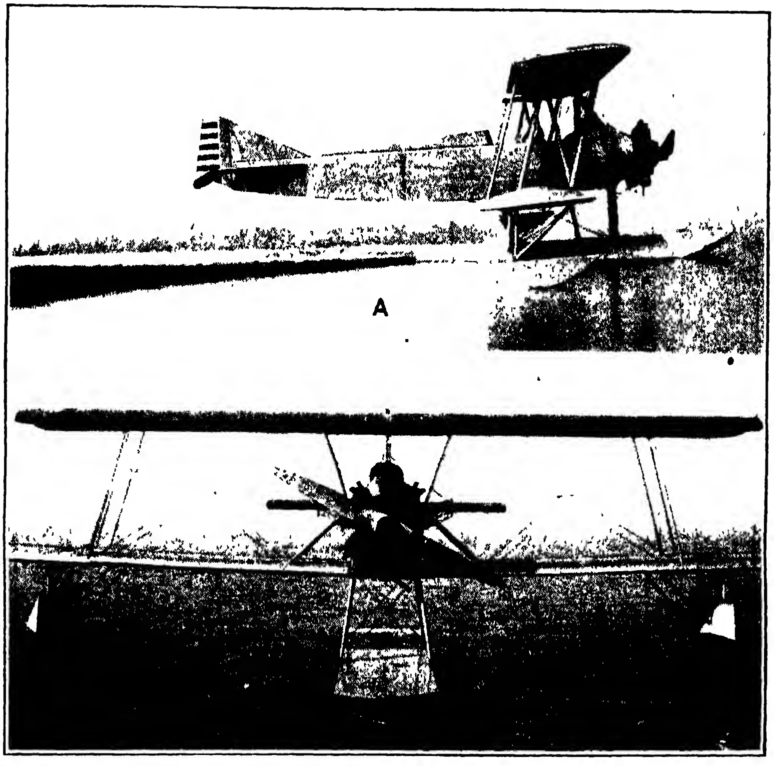


Fig. 339.—Two Recent Types of Single Float Seaplanes with Wing Tip Floats. A—Boeing Biplane, Side View. B—The Curtiss Lark Biplane Viewed from the Front.

Conflicting Factors In Float Design.—Commander H. C. Richardson, U. S. N. has sumarized the various conflicting factors that must be considered in seaplane float design as follows:

Seaplanes must meet requirements of airworthiness and seaworthiness. Airworthiness demands that the float system must be—

(a) As small and as light as practicable.
(b) Have good streamline form.
(c) Have little effect on balance, both statically and aerodynamically.

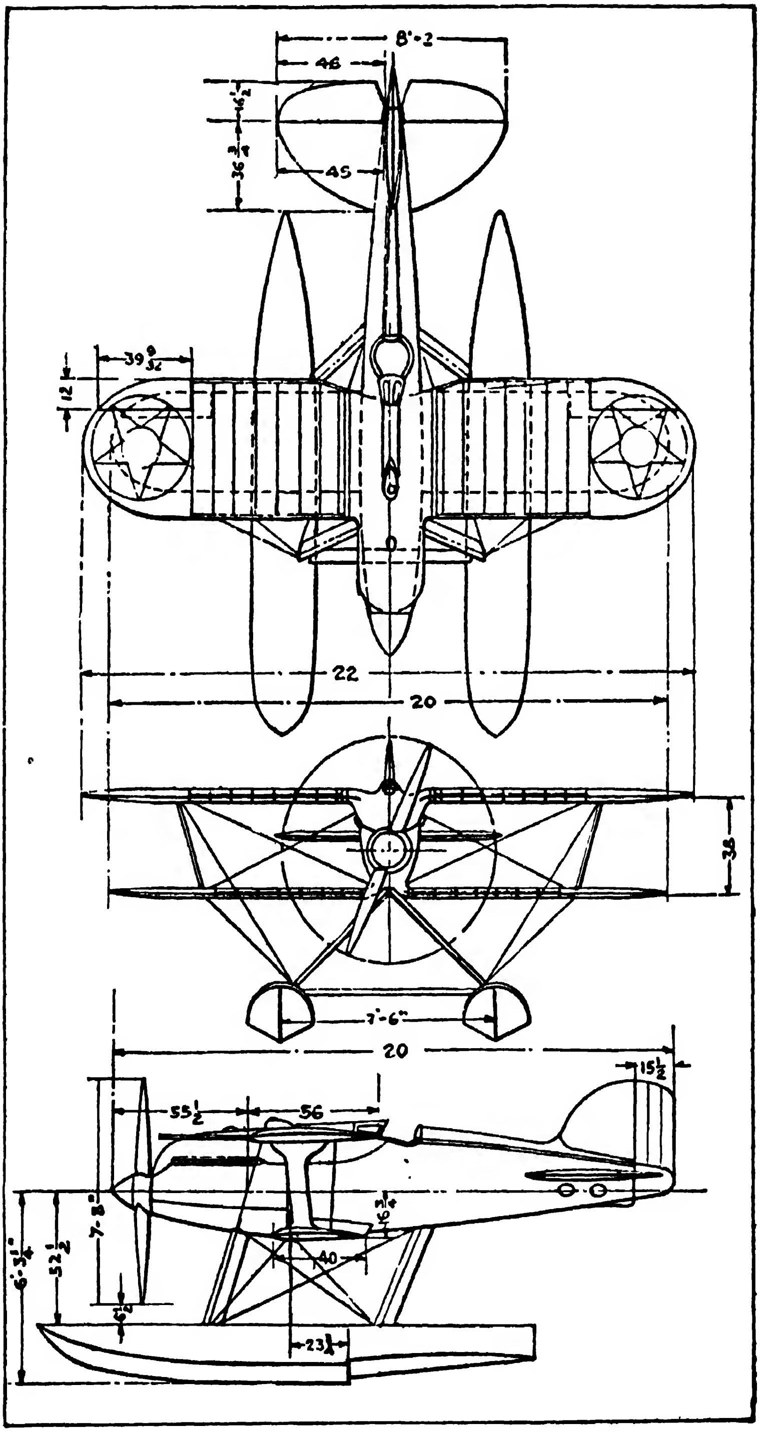


Fig. 340.—General Plan and Elevation Drawings of Curtiss Twin Pontoon Seaplane Racing Biplane.

Seaworthiness requires:

(a) Stability afloat, moored, adrift or underway, taxiing or towing.
(b) A proper reserve of buoyancy and stability.
(c) Minimum water resistance.
(d) Maneuvering ability, up, down and across wind and in a tideway.
(e) Ruggedness to meet the high forces encountered at "take-off" and landing, or adrift in a seaway.
(f) Simple construction and maintenance to facilitate fabrication, inspection and repairs.

A careful examination of these requirements will at once indicate a conflict requiring a compromise. A few comments will make this still more evident. Central floats require not less than 80 per cent reserve buoyancy. Twin floats require not less than 90-100 per cent reserve buoyancy. Boats as a rule inherently exceed these figures, but in doing so they usually combine the functions of float and fuselage. This excess is not chargeable in full part to the flotation system. Lightness in any form of floats can only be approached while utilizing material to the best advantages to provide essential strength.

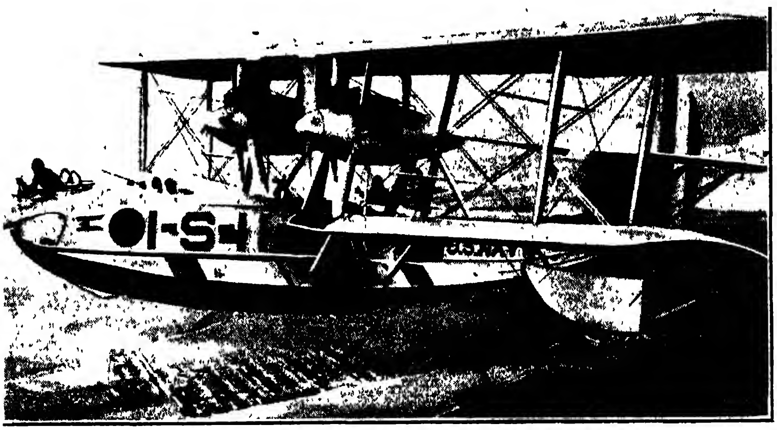


Fig. 341.—The P. N. 7 Boat Seaplane of the U. S. Navy Aircraft Squadrons in Flight. Note Boat Type Hull with Sponsons at Sides.

Advantages of Seaplanes.—Seaplanes have a marked advantage over land planes for commercial lines established between seaboard points or in districts, such as the Great Lakes section, where important commercial centers are located on fairly large bodies of water because no special airdromes or flying fields are necessary. Under such conditions they compete with boat lines and not express trains and they have a much greater advantage of speed as the ratio becomes 3 or 4 to 1 instead of 2 to 1 as is the case between a commercial land plane and a fast train.

Float Design and Surface Maneuvering.—Surface maneuvering under power is called taxiing. The float arrangement and disposition of engines has a complex bearing on this problem. Single screw ships usually turn

easily in one direction, but badly in the other, due to slipstream effects. Twin floats are more difficult to maneuver than single floats. Twin tractor or twin pusher or twin tandem types have a high degree of maneuverability when both units are available, but present special problems of seamanship if the power available is unsymmetrical. Central tandem engines afford perhaps more control than single engine types by utilizing opposite slipstream effects vailable from the tractor and pusher propellers usually rotating in opposite senses.

In the early days of naval development it was considered that 45 miles per hour was about as high a speed as should be employed for the "take-off" of seaplanes, but already big flying boats have been handled in moderate seas at over 70 miles per hour and racing planes have gone higher than 90 miles per hour. When it is considered that regardless of how much the wings are lifting the pressure per unit area is a function of the angle at which the surface is presented and the square of the speed, the need for ruggedness will be appreciated. In the cases referred to, wooden bottoms of a half-inch or less in thickness have successfully withstood such service. Adrift in a seaway, in a storm, it is more the sides of the floats that have to be considered, for the bottoms are, for reasons just cited, far more rugged than necessary for this requirement, and hogging and sagging stresses affect the hull trussing importantly. With twin floats, racking in and between floats is an additional problem of serious proportions, particularly underway in a cross chop or when crossing seas diagonally.

Features of Commercial Flying Boats.—There is no question but that multi-engine seaplanes are just as desirable as types having two or more motors flying over land. Some of the features that will be developed on commercial flying boats, as stated by Commander Richardson follow:

"Air-cooled engines are at least equal competitors in certain sizes today and may become even more generally used. Metal propellers, steel or alloy, will displace wood. In larger planes the central float is almost inevitable and the triple float arrangement will probably dominate. Sponson types are of inferior seaworthiness. In seagoing planes, the monoplane will probably dominate as the wings are less subject to damage in heavy seas, in case of a forced landing. For inland waters, the biplane may dominate and in such cases tip floats may be retained. Metal covered wings will only come slowly as the skin is disposed so that its weight is utilized to develop strength. Maintenance problems will also keep the cloth covered wing alive for years to come. Metal framed wings will soon be common. The hull will carry the empennage (tail surfaces). It will have hollow "V" lines at the bow, to form a good cruising bow, with good freeboard. It will have not more than two steps. The hull will be framed and plated with metal; alloy steel or aluminum alloy. It will be well subdivided and may incorporate double bottoms.

The fuel will gradually change from gasoline to heavy oil as Diesel type engines are developed. In the larger sizes, auxiliary engines may be employed for the handling of anchors and lines, drainage, lighting, signaling and propulsion afloat. On passenger planes, life rafts will be carried. Cruising speed will be in the neighborhood of 100 miles per hour. Landing speed will be under 50

miles per hour and maximum speed above 130 miles per hour. Cruising will be possible with one engine cut out. Pairs of engines will be frequently employed in tandem. High lift wings, with some form of flap to reduce landing speed, will be employed. On larger planes power will be used to operate the controls which also may be stabilized. Navigating equipment will include turn indicators, induction compasses and the usual position finding equipment. The prime requisite to development is demand, and demand rests upon dependability, which in turn means regularity and reliability.

Navy PN Series.—A very interesting series of boat-seaplane designs originated in the United States Navy and these craft have much to commend them for the work they were designed for. They were built at the Naval Aircraft Factory, Philadelphia, Pa. and are a development of the

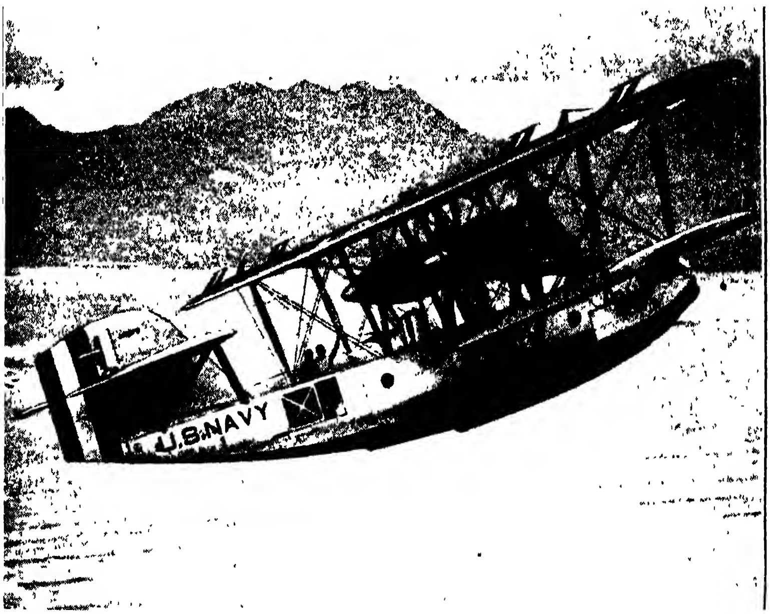


Fig. 342.—U. S. Navy P. N. 9 Boat Seaplane Going Up for a Scouting Trip.

F-5-L navy flying boats that have received such wide application in our Navy. The PN-7, which is shown at Fig. 341 uses a hull similar to that of the F-5-L but has a much cleaner wing construction with high lift wings and two Wright T-2 engines. The designation means that the PN-7 is a patrol plane designed by the Navy and the seventh of the series. The writer is indebted to the Bureau of Aeronautics, United States Navy for the following description:

The PN-7 is a twin-motored boat seaplane having a designed gross load of 14,800 pounds, a maximum speed of 105 miles per hour, a stalling speed of 58.2 miles per hour, a service ceiling of 8,000 feet, and a climb in ten minutes of 4,300 feet. The propelling machinery consists of Wright T-2 en-

gines built by the Wright Aeronautical Corporation of Paterson, N. J., and rated at 525 horsepower at 1,800 r.p.m.

General Dimensions:

Length overall, feet and inches	49-0 11/16
Height overall, feet and inches	18-1¼
Span upper wings, feet and inches	72-10
Span lower wings, feet and inches	72-10
Chord (both wings), feet and inches	9-0
Gap, feet and inches	9-4
Incidence (both wings), degrees	2
Stagger	None
Dihedral (lower wing only), degrees	3
Wing section	USA-27
Area of upper wings (including ailerons), square feet	675
Area of lower wings, square feet	545
Total wing area, square feet	1220
Ailerons (total area), square feet	120
Stabilizer, square feet	121
Elevator, square feet	55
Fin, square feet	54
Rudder, square feet	42

Engines (2) Wright T-2, 525 B.H.P. at 1800 R P.M.
Propellers.... D=10 feet 6 inches, P=5 feet 6 inches.
C. G. Location: variable with load, from 32 per cent to 34 per cent of mean chord.
Normal stabilizer setting 0 degree to thrust line.

Condition of Loading:—The conditions of loading ready for service in every respect, with full complement of officers and crew with their effects and consumable load is tabulated below for two conditions of operation, bombing and patrol.

Weight	Bomber	Patrol
Dead load	9850	9850
Crew (4)	720	720
Fuel	2046	2857
Oil	194	194
Flexible guns, etc.	265	265
Bombs	1065	0
Radio and accessories	285	285
Navigational equipment	35	35
Miscellaneous	210	210
Gross load	14,670	14,416
Pounds per square feet	12.02	11.82
Pounds per B. H. P.	13.97	13.73

Complement:—The complement consists of four men; the first pilot, the relief pilot, a mechanic-gunner, and radio operator.

Armament:—The armament consists of: 4 Lewis guns, 12 Lewis gun-97-round ammunition boxes, and 1 Colt revolver with 28 rounds of ammunition; 1 bomb sight, 4 bomb gears and bombs of type prescribed.

Anchor Gear:—The anchor gear consists of one 80-pound anchor and about 25 fathoms of line. These are to be carried only when necessary.

Fuel Stowage:—The total gasoline capacity is 489 gallons and the fuel is

stowed in five tanks. One hand gas pump and two windmill pumps are fitted. These deliver gasoline from the tanks to a gravity tank in the center section of the upper wing whence it flows by gravity to the carburetors and, through a sight-feed glass in the overflow line, back to the tanks. The total lubricating oil capacity of 30 gallons is carried in two tanks, one in rear of each engine.

Communication Equipment:—The following communication equipment is installed: One radio set with directional compass; one inter-communicating set; 1 Aldis lamp; 1 Very pistol and ammunition; hand semaphore flags.

Navigating Equipment:—The following navigation equipment is installed: Drift indicator, compass with azimuth circles, chart board and charts, sextant, torpedo boat watch, universal drafting machine, instrument case, and navigation books.

Miscellaneous:—Miscellaneous equipment is provided as follows: Bilge pump, discharge and suction hose with strainer, hand fire extinguishers and pressure Pyrene, tool kit, canvas bucket, first aid kit, parachutes, life jackets and emergency rations.

Development of the PN-10 Flying Boat.—Experience gained from the Navy's experimental PN-9 "flying boats" has resulted in a further development of this type of patrol airplane—the PN-10. These new biplane, tractor, boat seaplanes, with their two Packard 600 horsepower engines, are being built at the Naval Aircraft Factory, Navy Yard, Philadelphia. They are a development of the old wartime "flying boat," the F-5-L which is still in service. This design can be traced back to the "America," the first two-motored flying boat in this country, which was built at the Curtiss plant, Hammondsport, New York, and completed in July, 1914, when she made a flight with ten men aboard—a record for passenger carrying. She was supposed to make the first transatlantic flight in October 1914 and was to have been piloted by Lieut. J. C. Porte of the British Navy. Later the "America" was purchased by the British Navy and used in training pilots for the Royal Naval Air Force. The F-5, developed by the British was undoubtedly an outgrowth of the trials made with the "America." Then came our Navy F-5, built for the famous Liberty Engine, and called the F-5-L.

These airplanes have made many interesting long-distance flights, the first of importance after the war being at the end of 1919, when Lieutenant Commander B. G. Leighton, now Aide to the Assistant Secretary of the Navy for Aeronautics, was in command of six F-5-L flying boats which made a West Indies cruise from Philadelphia via New York in connection with the winter maneuvers of the Scouting Fleet. This cruise of 13,000 miles was made without a single mishap. The total mileage of these six planes was 71,545, nautical miles and the total flying time was 1,920 hours. The following winter twelve F-5-L flying boats made a 3,200 mile flight from San Diego to Canal Zone under the command of Captain Mustin. Next came the F-6-L with minor design experimental changes. Then came the PN-7 with the conspicuous changes in the installation of the new higher powered engines in the graceful streamlined engine nacelles, which greatly reduced the resistance of the airplane. Another move to lessen the re-

sistance was the reduction of the interplane rigging. The least conspicuous change, but perhaps the most important, was the change to a high lift wing section, decreasing the span and area. By these alterations, speed, efficiency, and lifting capacity, which is of such great importance, were all greatly increased.

The next step—the PN-8—was to try an all metal hull. This gave a saving in weight of about 500 pounds and eliminates soakage in service. A few minor improvements in design were made, and all metal empennage was added, and the two now famous PN-9 boat seaplanes were ready to start on their Hawaiian flight under the command of the late Commander John Rodgers. The changes from the PN-9 shown at Fig. 342 to the PN-10

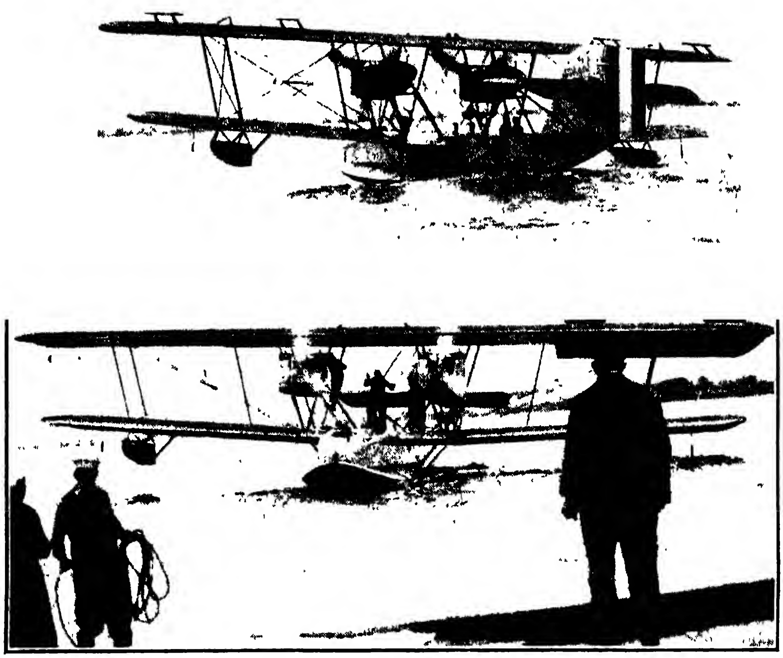


Fig. 343.—Front View of U. S. Navy P. N. 10 Boat Seaplane Making a Landing at Bottom and Rear View of the Same Plane at Top Just before Taking-off.

shown at Fig. 343 (Airplanes A-7028 and A-7029) will not be visible to the casual observer, but to the designer and engineer they are of great importance. There is a difference in the wing setting of the two models—increasing of the angle of incidence from two degrees to four degrees. A model of the PN-9 with increased setting was run in the wind tunnel and it was found that the stalling angle of this type airplane would occur at 20 degrees, whereas the F-5-L type stalled at 16 degrees. This necessitated certain design changes in the tail group. The normal setting of the horizontal stabilizer was changed—an increase of 2 degrees, from 1 degree 45 minutes to 3 degrees 45 minutes; a decrease in the area of the rudder balance from 4 square feet to 3 square feet. There were many minor

changes in the internal hull construction, increasing of the "water-tightness" and lowering the gun ring flush with the deck. The pilot's cockpit opening has been extended forward about eight inches to allow better arrangement of the cockpit, which has been enlarged, and slight changes made to improve the visibility. The radiators have been completely redesigned and increased to 60 gallons each.

The new Packard 2A-1,500 engines have increased the power from 500 horsepower at 2,100 r.p.m. to 600 horsepower at 2,500 r.p.m. Metal propellers have been substituted for the wooden propellers used on the PN-9s, lessening vibration and increasing performance. The gasoline tanks are similar in size and arrangement to those of the PN-9 with the addition of a 70 gallon tank under the pilot's seat, giving a capacity of about 1,330 gallons. There is storage space in the hull for the carrying of extra five gallon cans if desired. An idea of her size may be had from her dimensions. Her wing span, or width, is nearly 73 feet; her length slightly over 49 feet, and her height is about 16½ feet. As a service plane she is designed to carry a crew of five with a full load of 18,000 pounds; but she was flown in tests with a full load of 21,000 pounds, giving her a useful load of approximately 11,800 pounds.

Boeing PB-1.—This is a patrol type boat seaplane designed and built by the Boeing Aircraft Factory, Seattle, Washington for the United States Navy and is illustrated at Fig. 344. The data furnished by the makers follows:

The arrangement of the hull is very similar to that of the PN-9. In the bow is the navigator's compartment, a small space so fitted and equipped that the navigator can make observation of both celestial and terrestrial objects to obtain the ship's position, the course to be steered and all other vital factors which are plotted on a chart board within the compartment.

Behind the navigator's compartment and adjoining by a small door, is the pilot's cockpit well forward in the hull and equipped with dual control. As in the PN-9, the gasoline tanks are situated in the center portion of the hull aft of the pilot's cockpit, together with the mechanic's station, behind which is located the radio compartment, the equipment of which is similar to that on the PN-9.

The plane is slightly larger than the PN-9 in construction, having a full load weight of 24,000 of which 12,531 pounds or 52.3 per cent is useful load. The wings have a total area of 1,301.5 square feet with a span of both upper and lower wings of 37 feet 6 inches, and a chord of 11 feet. The gap between the wings is 13 feet 5 inches, and the set angle of incidence is zero. There is no stagger or sweep back and while the upper wing is flat there is a dihedral of 4 degrees on the lower.

The hull of the PB-1 is of the NC type with an F-5-L tail. The construction of the hull is one of the outstanding features of the plane, it being constructed of duralumin up to the water line, above which is plywood, this unique design reducing the weight and eliminating much soakage.

The design of the PB-1 incorporates several outstanding features, important among which is the placing of the two 800 horsepower Packard engines in tandem between the wings, thus enabling one of the engines to be

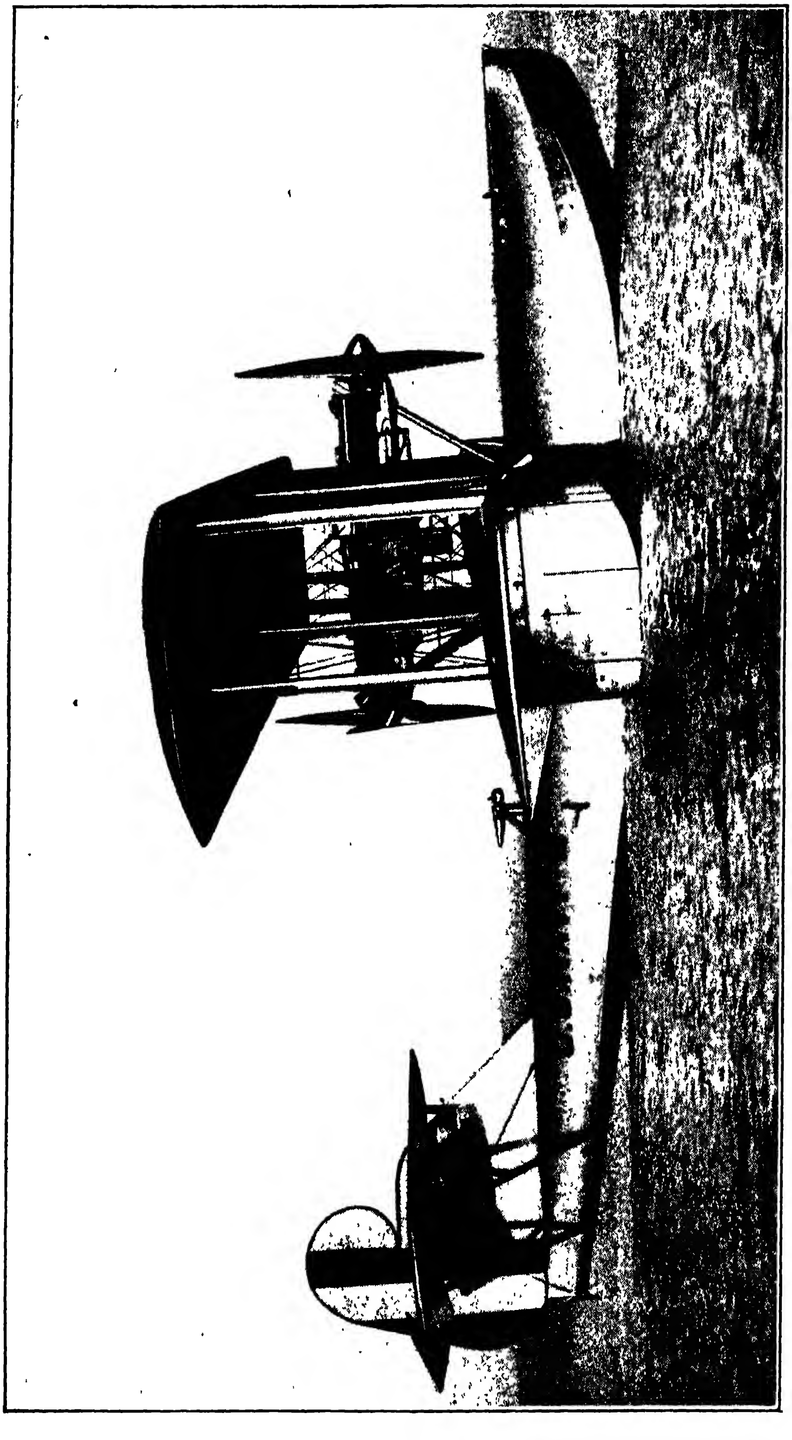


Fig. 344.—Side View of Boeing P. B. 1 Boat Seaplane Showing Tandem Engine Mounting.

shut down for minor adjustments when in flight. Each engine drives a four bladed propeller built by the Hamilton Propeller Company.

The characteristics of the PB-1 are especially interesting when compared with those of the historic NC type which made first transatlantic flight in 1919. The weight of the NC was 28,000 pounds and its range in the neighborhood of 1,600 miles, whereas the Boeing PB-1 has a fully loaded weight of 25,000 pounds and a range of 2,500 miles, nearly 1,000 miles greater. Further, the NC wing span was 126 feet while that of the new PB-1 is but 87 feet 6 inches. Of the total weight, 11,000 pounds can be carried as fuel, representing nearly 1,800 gallons of gasoline. Five men compose the crew of the plane, though accommodation is available for seven. The plane has a maximum speed of 125 miles per hour, a stalling speed of 66 miles per hour and a cruising speed of 80 miles per hour, and is able to climb to 5,000 feet altitude in 10½ minutes. It can remain in the air full speed 11.9 hours or at cruising speed 23.7 hours.

Requirements of Navy Seaplanes.—In a discussion of Development of Naval Aeronautics, before the S. A. E. Commander H. C. Richardson, U. S. N. outlined some of the requirements of modern seaplanes and flying boats used by the navy. The demands made upon airplanes of all classes are continually becoming more exacting, said Commander Richardson. They must carry more and heavier bombs, machine guns, ammunition and radio sets; must go faster, climb higher and remain in the air longer; must be designed for minimum structural weight yet sturdy enough to withstand landings and take-offs in heavy seas and to ride out storms at buoys; must be braced against the high acceleration of catapulting and the deceleration of deck landings; must be easily maneuverable; have a minute turning-circle, a quick take-off and slow landing speed; must go into a tail spin easily and come out of its own accord; must have sufficient stability to fly "hands off" yet must answer its controls with lightning speed and precision; must have ample space for the comfort of each member of the crew and unobstructed vision in all directions; must protect the personnel against injury in case of possible crashes; and must have reinforcements and braces so that heavy-footed mechanics can clamber about it without damaging it unduly. Bombing airplanes must have all the instruments for discharging bombs arranged in orderly fashion and readily accessible behind a glass window fitted with a windshield wiper; must carry parachute flares, landing-lights, smoke bombs, baggage of the crew, emergency rations, anchor and line, engine tools, and spare parts; must have folding wings to allow ready stowage aboard ship; and must allow rigging for flight in 3 minutes. When rigged the total wing-spread must not exceed the dimensions of the elevators used to hoist the airplane to the flying-deck of the carrier. The hull or floats of flying-boats must not soak up water, when anchored for an entire season, yet, if made of metal, must not corrode.

The power plants, including not only the engine and propeller but also the fuel, oil and water systems with all tanks, pumps, piping, coolers, and heaters, continued Commander Richardson must fulfill many requirements also. The engine must weigh not more than 1¾ pounds per horsepower yet must be rugged enough to run 300 hours between overhauls without breakdown, though running a large part of the time at nearly full power.

The fuel, oil and water pumps must be light, compact and reliable. The propeller must be thin enough to be light and efficient, yet must withstand the attacks of spray and rain. The fuel and oil tanks must not leak under constant vibration, must be made of a material not affected by benzol or ethyl fluid, yet they cannot be of copper or tinned iron, because these materials are too heavy. A device must be provided for heating the oil quickly when starting, yet must keep the oil cool during flight. The radiator must be of the lightest design yet leakproof, must be located where it will produce the best cooling yet not interfere with the pilot's vision or cause undue air-resistance or be a menace to the pilot in a crash.

Where Progress Is Being Made.—Progress has been made, he said, along three principal lines: aerodynamics, structure and suitability for the purpose intended. Advances in aerodynamics have consisted mainly in refinements of details and ingenious rearrangements of wings, control surfaces and their bracing. In structural progress, the trend has been toward the substitution of metals, such as duralumin, for wood.

In adaptation to specific purposes, Commander Richardson explained that the five classes of airplane being developed for the Navy comprised airplanes for training; for fighting or pursuit; for gunnery observation or short distance scouting; three purpose airplanes for torpedo dropping, bombing and long distance scouting; and patrol airplanes. Development of the engine and of the power plant accessories has resulted in decreasing the weight of the engine; in increasing its power, reliability and ruggedness; and in the use of supercharges and metal propellers. Experiments now being made in aeronautics are along the line of reducing the take-off and landing speeds, of reducing the drag in seaplanes by designing floats offering less air resistance, of operating the control levers by motors in much the same manner as the steering gear of ships is now operated, of developing some process for preventing the corrosion of duralumin, of using adjustable pitch propellers or supercharged engines, and of reducing the excessive air resistance and weight of large water-cooled engines by a method of steam-cooling.

Looking into the future, Commander Richardson said that the tendency is to abandon the float type, or seaplane, in favor of the hull type, or flying boat, because of the greater seaworthiness of the latter. The three purpose airplane will probably be superseded by three distinct types as the numbers of aircraft in the Navy increases, in other words, the scouting will be done by amphibians of long range, the bombing by land airplanes of good climbing ability, and the torpedo launching by flying boats of high speed.

Giant Flying Boats.—It is difficult to predict just how large airplanes of the boat type can be built in the future and various designs are projected that are of much greater size than anything that has been built to date. The Dornier Superwal commercial seaplane shown at Fig. 345 is an example of a large craft of this character. It carries 21 passengers and a crew of four, consisting of two pilots, one mechanic and a radio operator. It is a braced monoplane type, the hull being supplemented by sponsons of aerofoil section at each side that assists in keeping the hull afloat when on the water and which contribute useful lift when in flight. There are two cabins, separated by a baggage hold, the front cabin seating 13 passengers,

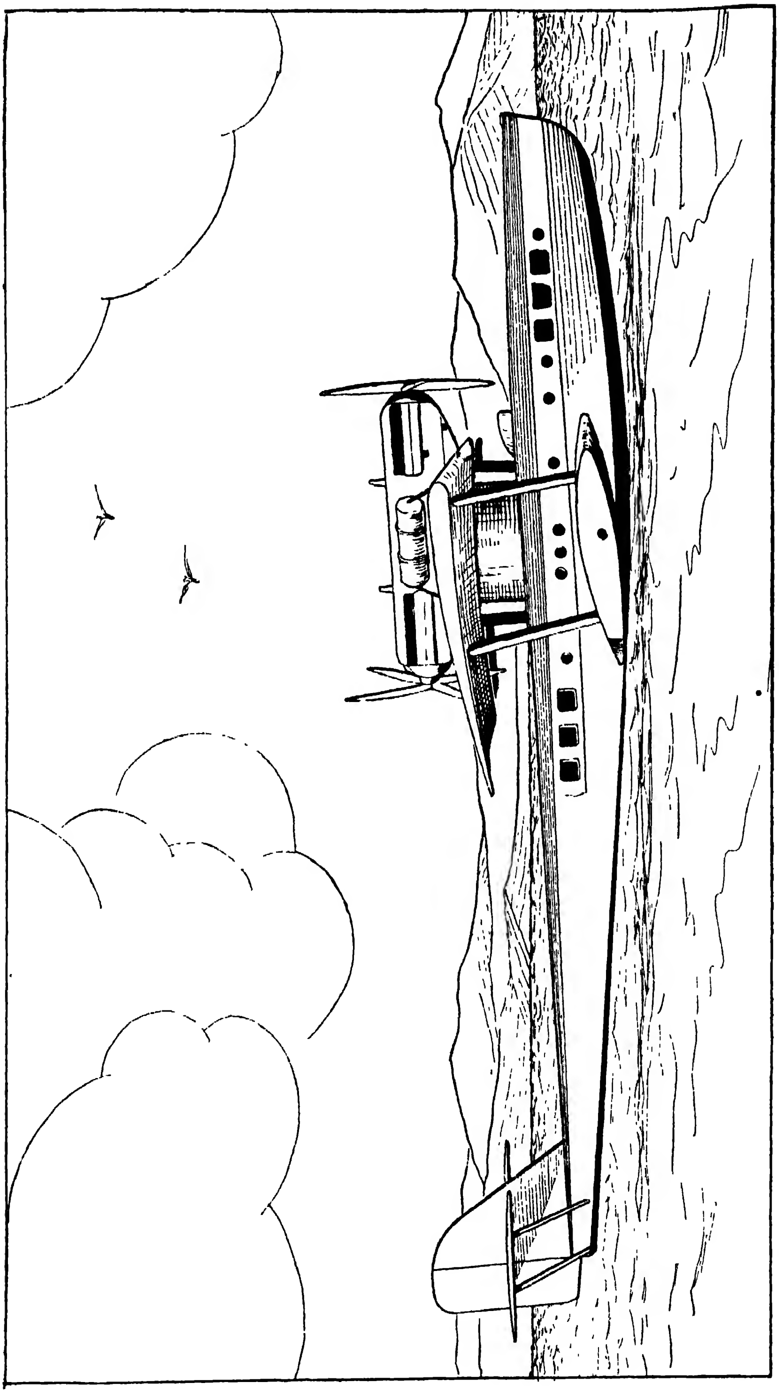


Fig. 345.—Dornier Superwal all Metal Commercial Boat Seaplane of the Monoplane Type Carries Twenty-One Passengers and Crew of Four. It is Equipped with Two 650 Horsepower Engines, Mounted Tandem above the Supporting Aerofoil.

the aft cabin having accommodations for 8 people, two Rolls Royce engines of 650 horsepower each are carried in a nacelle above the wing structure. The maximum speed is 118 miles per hour. It has a span of 94 feet and a chord of 18 feet. The main wing has an area of 1,539 square feet. The weight empty is 12,840 pounds, loaded 20,800. The loading is 16 pounds per horsepower and 13.5 pounds per square foot. The construction is all metal. The overall length is about 88 feet.

In order to build very large seaplanes, constructors have proposed to do away with the airplane wing as such and to use a central, hollow body of metal having wing like or aerofoil section extensions capable of exerting lift when in the air. The only external projections would be the floats or hulls and the necessary control surfaces. As these craft would be of very large span, double hulls might be provided. The crew, passengers, engines and fuel would be contained in the hollow metal structure, which being of aerofoil section and consequently self-lifting, would serve the double purpose of hull and wing. By using an all metal construction, the giant seaplane might be built lighter than would be possible with wood or composite wood and metal structures.

Superboats by Junkers, Rumpler and Ricci Bros.—Superboats are in construction intended to carry 100 passengers and driven by 12 large engines. Professor Junkers is said to be assembling main sections at Dessau, Germany, of a large seaplane that is reported to have one tremendous aerofoil of monoplane form 240 feet in span, and that will be driven by engines totaling 4,000 horsepower. It is estimated that it will be able to fly at a speed of 125 miles per hour when carrying as many as 112 people.

Dr. Rumpler, another of the most successful of the German airplane manufacturers is also working on a large seaplane that will incorporate new principles in structural design and weight distribution. He claims such a ship will be able to fly from Berlin to Rio de Janeiro, in about 80 hours allowing for stops. Steamships require 3 weeks to make this trip. Another journey in which the time will be greatly reduced is from Hamburg to New York which will require 36 hours, including a 5 hour stop-over at the Azores Islands. The new Rumpler craft is to have 10,000 horsepower, obtained from 10 motors of 1,000 horsepower each. It will carry 136 passengers, nearly 7 tons of freight or baggage and 86,400 pounds of fuel and oil. The speed will be 270 kilometers per hour or about 128 miles per hour.

The Ricci Brothers, Italian constructors, propose to build a quadruplane to carry 150 people and 14,000 pounds of cargo, equipped with eight 600 horsepower twelve-cylinder V engines.

This giant is to have wings with steel spars and duralumin ribs surfaced with nickel-chrome steel; tail and control surfaces are the same. Its engines are located in couples at the front and back of the nacelles and transmit power independently of each other to two metal four-bladed tractor screws and to two propellers. These nacelles are on the second plane, counting upward, and in the same vertical plane as the two floats which contain the tanks for fuel, etc., and at their extremities carry a biplane tail. The center parts of the nacelle form the engineer's cockpits, and the vessel will be controlled from the center bridge above the second floor of the

saloon, which is of the height of the gap between the planes, and the floor of which is on the level, or will actually be part of the center section of the second plane. A 4,000 horsepower triplane, which seems to be a sort of aerial barge, has also been developed. This has two sets of planes parallel with each other but not in the same horizontal plane, the rear set being placed at the distance of their chord from the front set, but appreciably higher—that is to say, farther from the boat body. All six wings have rounded ends at the entering and much swept ailerons at the trailing edges.

Amphibian Planes.—One of the major problems confronting the aeronautical engineer and demanding solution is the removal from the airplane in a practical way of the limitation of landing conditions due to having seaplanes that are unfit for use over land and land airplanes that are totally unfit and dangerous for use over water. Spreading like an ocean over every locality as it does, the air is claimed by many to be the great future highway for quick transport and yet, after 20 years of intensive airplane development, we are only now beginning to realize the full significance of the development of amphibious airplanes. Until we endow the airplane with the facility of landing and of starting anywhere, we limit and restrict it at the start and fail to provide it with its most essential fundamental as a vehicle suited for universal usage.

One of the pioneer American aeronautical engineers, Grover C. Loening, M. S. A. E., in a paper read before the society considered the subject of amphibian airplane development in an authoritive manner and inasmuch as he is the designer of one of the most practical planes of this type yet evolved, the writer feels safe in presenting portions of Mr. Loening's discourse and using the Loening Amphibian as a typical modern example of this type of construction. He said in part:

"The delay or lag in the development of amphibious airplanes a few years ago was due to the simple fact that the general trend of development had been the obvious one of adding wheels to a flying boat or floats to a land airplane, the net result being that no improvement was made to either and complication, head resistance and weight were added. Therefore, to the critical air pilot who finally had the say regarding what types achieved success, the amphibious airplane had come to mean a heavy cumbersome 'crate' and, in almost every case, for years, its development had meant merely that a good seaplane was spoiled by trying to add wheels to it, or a good land airplane was made more cumbersome by trying to make it over so that it would float. The development of the Loening Amphibian started, therefore, with perhaps the first definite recognition that to make amphibious airplanes successful required the initial design of a totally new type of airplane, amphibious in its very inception and complete in proper characteristics for land or for water operation from the very start. That we have apparently succeeded in building a fundamental type of airplane that has reopened the entire field of use of amphibians probably is due to recognizing this necessity. The air pilot has been pleased simply because nothing has been sacrificed in performance or handling and, fortunately, in this new type, a strictly land type of airplane has been obtained which has exceptional qualities of its own, were it never to see the water, and a desir-

able tractor type of flying boat long sought after and full of seaplane advantages has been developed were it, in turn, never to see the land.

Disadvantages of Old Amphibious Designs.—In general, we can summarize the disadvantages of the general amphibian developments that had taken place up to the advent of our new type, to consist essentially of the following points:

(1) Poor flying qualities. Slower and heavier handling as a seaplane and more head resistance in the air and on the water, due to the external attachment of the landing gear.
(2) Dangerous as land airplanes, particularly in the flying boat types of amphibian in which the engine is over the crew. The wide distribution of heavy weights, with the crew located in the bow of the airplane, constitutes a distinct menace over land. In addition, the propeller at the rear is a danger, and the weight being very much higher off the ground leads to difficulty in handling.
(3) The amphibious construction had not given any mutual advantage either to the land or the seaplane types.
(4) Poor efficiency and maintenance, and therefore highly expensive operation and less performance.

This was the situation as we analyzed it several years ago and, fortunately, the successful development of the inverted Liberty-12 engine at McCook Field late in 1923 gave us a splendid power plant of the type for which we had been clamoring so long a time; so, we proposed to the Army Air Service the construction of this new and novel type of *tractor amphibian* with the hull and body complete as a unit, using an inverted engine with the propeller thrust at the extreme top of the body as shown at Fig. 346."

Loening Amphibian Has Excellent Performance.—Mr. Loening states that with the same power plant as used on the DH airplane and with an additional weight of from 100 to 200 pounds, this amphibious flying boat could out-climb, out-manoeuver and out-speed the DH airplane in every item of performance and that this was the first time any seaplane had performed better than a land plane. There is no fundamental waste of weight or duplication in the design, and even the external part of the landing gear, the wheels and the small elements fastened to the edges of the hull, amounts only to about 180 pounds, all the interior hull framing being required in any case as part of the support of the airplane on the ground. The greatest practical advantage to the airplane has been found to be the extraordinary amount of room in the unit body and hull. This type of airplane has been looped and spun and stunted in exactly similar manner and as easily as the best land airplane of equal weight.

Interesting Structural Details.—Among the interesting and important constructional details, mention should be made of the electrical operation of the retractible wheel landing gear, which takes only 4 or 5 seconds, and the hull construction that is entirely metal covered throughout, using duralumin, which is fastened by duralumin bolts to wooden stringers, giving a remarkably water-tight and serviceable job. Great care is taken to separate the duralumin sheet and the wood by a layer of fabric impregnated with bitumastic. The use of

bolts instead of rivets or wood screws is the result of a very careful study and is particularly desirable in that it makes the protection of the bolt against corrosion in salt water much easier, because each individual bolt can receive numerous coatings of enamel or bitumastic, if desired and, in being fastened to the hull, it is not hammered like a rivet and therefore is not likely to lose its heat-treatment against corrosion. Up to now, only one coat of bitumastic has been used on the bolts, and airplanes that were 5 months out at sea with the Navy's Arctic Unit and subject to severe weather conditions, came back in remarkably good condition. However, any amount of protection can be given the bolts, which is not true of rivets. The wood frame seems to have enough resiliency to take up the severe local strains of the land operation of this airplane to prevent leaks from developing, which has always been a serious cause of trouble in amphibians.

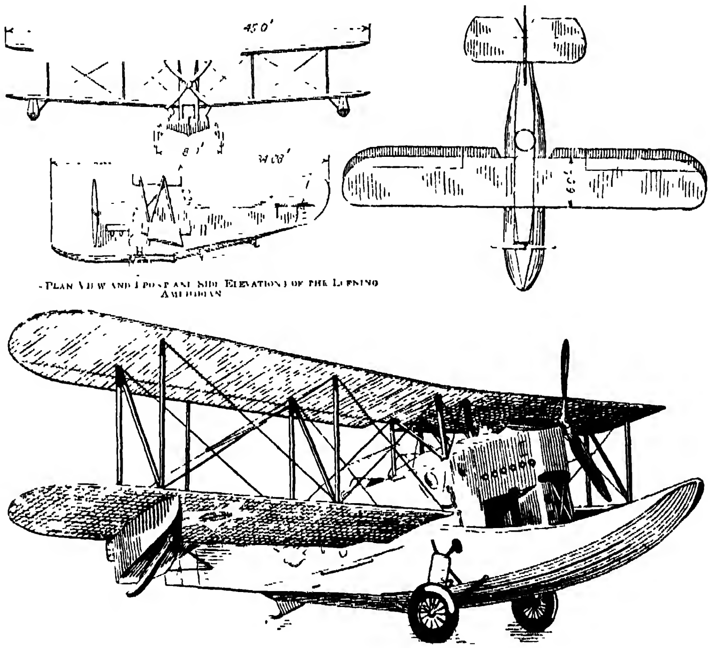


Fig. 346.—Plan, Elevations and Perspective View of Loening Amphibian Airplane Used by United States Army and Navy, the Most Recent Development of this Type Aircraft.

The wing structure is metal framing, covered with linen. The ribs are made of duralumin by a machine-tool process, specially developed in our shops. Table XXII gives comparative weights and performances for several types of amphibian. From this it will be seen that, although its safety factor is considerably higher than that of any of the airplanes listed, the Loening Amphibian is 10 or 15 per cent lighter than any of the older types, none of which, however, are built in any way of metal construction. This new type of airplane, shown in Fig. 346 has been ordered by the Army Air Service, by the Bureau of Aeronautics of the Navy and by the United States

Marine Corps for a wide variety of uses. It is an excellent airplane for photographic purposes; it is useful as a coastal reconnaissance airplane and is an ideal cross-country machine, as well as being a type that is suitable for use from shipboard on aircraft carriers. Evidence of the versatility of this type of airplane is found in the records of expeditions and in cross-country trips already made within the past two years.

In cross-country flying, we hardly need argue the enormously greater factor of safety due to having double the possible landing places in case of emergency. In fact, even a greater element of safety exists since, in thick weather, river courses can be followed in many sections with ability to land at almost any time. We talk of mapping out airways, and yet, so far as amphibians are concerned, we cannot have finer airways than we have on the Coast, marked as they are so distinctly that one cannot miss his way in thick weather, nor can we have better lines of travel than over the Hudson, the Ohio, the Mississippi, the Missouri, and other rivers. There are, therefore, three cardinal advantages of the amphibian for commercial work. First, time is saved by having the terminal at the city all ready-made for it; second, danger of cross-country flying is greatly lessened by the use of this type; and third, money is saved to commercial enterprise by not needing extensive landing field property acquirements.

TABLE XXII

Characteristics of Various Amphibian Planes

Airplane Type	Engine Type	Power, Hp.	Area, Sq. Ft.	Span, Ft.	Weight Empty, Lb.	Maximum Load, Lb.	Full Load, Lb.	Weight per Horsepower, Lb.	Weight per Square Foot, Lb.	High Speed M. P. H.	Service Ceiling, Ft.
Sperry Triplane........	Liberty-12 ...	500	678	48	4,199	1,345	5,544	15 0	8 0	85	9,000
Fairey	Napier Lion..	450	488	46	3,900	1,600	5,500	12.2	11.2	108	13,000
Vickers IV....	Napier Lion..	450	635	50	4,030	1,760	5,790	12 8	9 1	105	13,000
Supermarine Scarab.....	Napier Lion..	450	605	46	4,125	1,875	6,000	13.3	10 0	103	11,000
Schreck FBA..	Lorraine ..	450	535	47	4,150	1,990	6,140	13 5	11 3	109	14,000
Loening Amphibian.....	Inverted ...	400	504	45	3,400	1,800	5,200	13 0	10 3	124	15,000

The Autogiro Rotating Wing Airplane.—This unusual machine, shown at Fig. 347, while it has the appearance of a helicopter, it operates more on the principles of flight that govern the sustentation of airplanes. The machine has a fuselage with engine and propeller like a conventional plane, but instead of having fixed wings, it is sustained by a four-bladed air screw supported on a mast above and in front of the pilot. This wind vane is not driven by the engine, but rotates freely because of the pressure of the air slipstream of the propeller. This machine was invented by Señor Juan de La Cierva and has been tested and flown in France, Spain and England.

The machine is based on principles entirely different from those followed in the construction of helicopters. A helicopter is sustained in flight by a lifting propeller, which an engine causes to rotate in a horizontal plane and it "lifts off" vertically. In the Autogiro, the big four-bladed pro-

peller is not actuated by any power plant, but, instead it is made to turn freely on its bearings. Consequently, this " screw" is actually a wind vane, which operates like the little propellers used to actuate the fuel pumps of

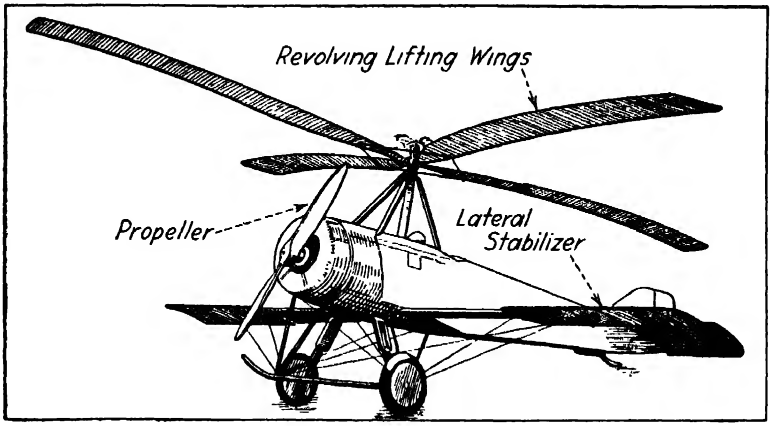


Fig. 347.—The Autogiro Revolving Wing Airplane Differs Radically from the Usual Design.

aircraft engines, that is, it is the relative wind created by the forward motion of the airplane that causes it to revolve.

On the Autogiro, the big wind vane is mounted in ball bearings and is not controlled in any manner by the pilot. The blades of the vane are set at a fixed angle of incidence relative to the axis of rotation, but they are hinged to the bearing shaft in such a way that in flight they place themselves according to the resultant of their lift and centrifugal force.

The mechanism, which is used to equalize the loadings between vanes, is nothing but a free hinge at the inner end of the spar of each vane. The

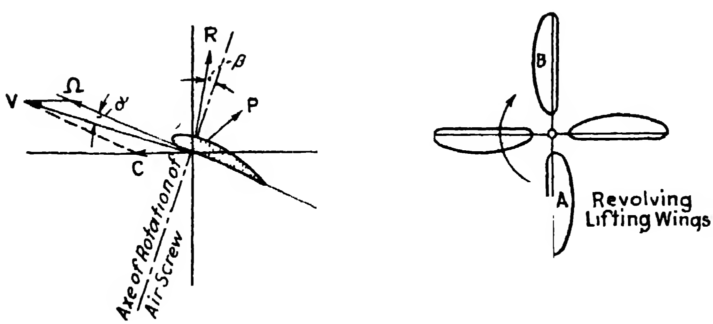


Fig. 348.—Diagrams Showing Principles of Sustentation by Revolving Wings Employed in La Cierva Autogiro, an Unconventional Type of Aircraft.

hinge would permit the vanes to fold downwards, were they not supported from above by wires and rubber shock absorbers. The vanes are perfectly free to fold upwards. The angle of incidence of the blades is fixed, but

incidence adjustment is secured automatically in the method of hinging the vanes. If a pair of vanes are considered when the spans are fore-and-aft, air speed is due to rotation only. As the vanes revolve, the air speed is increased by the forward speed of the machine and this tends to augmen the life on the aft vane. The vane folds up and decreases the incidence. The forward vane, has its air speed decreased as it moves around and as it falls, it increases the incidence.

Principles of Autogiro.—The principles of operation may be more easiiy understood by referring to Fig. 348. Experiments made with a stationary propeller exposed to an air current in the position A, show that the blades have a resultant R which makes an angle with the propeller shaft. The resultant P of the opposite blade (position B) has always a smaller angle than A or is negative. Therefore, a rotation is established by the propeller in the sense of the arrow. The speed of rotation will increase until the resultant of R and P is parallel to the axis of rotation of the propeller. The whole lifting body does not transmit to its shaft any torque except the one produced by the friction of the bearings, which can be neglected, eliminating, therefore, the necessity of using two propellers.

However, the resultant velocity of the blades relative to the air in position A is greater than in B and its life will be greater also. Therefore, the total resultant of this propeller will not pass through its center and the whole system will tend to bank. This banking effect has been overcome in the Autogiro by fixing the blades to the shaft by means of a hinge, which permits them to set themselves automatically in the resultant position of the centrifugal force and the lift. In this way, blade A will bank slightly, while blade B will remain horizontal and the total resultant of the lifting propeller will always pass through its center.

The velocity of the blades relative to the air is much greater than the translational speed of the whole machine. The angle of attack is a function of the translational speed of the machine and the angle between its direction of motion and the plane of rotation of the blades. This allows a much greater range of speeds and angles of flying to the whole machine, and will permit landings in very small spaces without horizontal motion. The Autogiro weighs about 880 pounds empty and 1,100 pounds loaded. The horizontal speed attained is from 38 to 55 miles per hour. The rotational speed of the lifting vane is about 140 r.p.m. in horizontal flight. The descending speed in vertical landings is of about 6-10 feet per second. The control of the machine horizontally is by means of the usual vertical rudder. The elevators operate to control the machine in a vertical plane just as in more conventional craft. Out riggers extending from the sides of the fuselage carry ailerons for lateral balance and these are controlled just as in an airplane. To start the machine, the wind vane is set to rotating by means of a mechanic who pulls a rope wound around a suitable frame, this spinning the wings, after which they will be kept in motion by the air stream of the propeller. It is stated that in making a forced landing with the "stick" dead that the vanes continue to rotate and act to retard fall of the plane due to the gravitational pull and the machine is said to be almost stall proof. It is still in the experimental stages and its development is being eagerly watched by aeronautical engineering circles.

Helicopter Principles.—Two other classes of heavier-than-air craft have been experimented with besides the airplane but these have not met with great success. On type, known as the "ornithopter" we can dismiss with very few words as while this machine offers interesting mechanical problems for solution, its practical application has been nil. This general class includes all machines that hope to rise and sustain flight by wing flapping mechanism so that they will fly as the smaller birds do. It is difficult for man to devise mechanism that will be simple and reliable that will duplicate the complicated compound movements of the internal structure of a bird's wing that are necessary to secure sustentation and flight combined with a degree of directional control at the same time.

The helicopter classification includes all machines which are to be lifted and sustained in the air solely by rotating air screws. The lift is secured by the lift reaction or thrust of the propeller blades rather than by air acting on planes or aerofoils inclined at an angle to the direction of motion of the machine. The helicopter idea is as old if not older than the airplane and thousands of small toy helicopters ascended into the air long before airplanes did, though the airplane in the form of a kite is probably the oldest flying machine because of the experiments carried on centuries ago by the Chinese. The advantage claimed for the helicopter over the airplane must be in its ability to rise and descend vertically and to hover over a given spot. As far as our present knowledge of helicopters is concerned, its ability to maintain itself in the air is due entirely to the power of the engine and should the power plant fail, the machine would come down very fast unless its descent was checked by some auxiliary such as a parachute or allowing the propellers to rotate so they would offer some degree of resistance to impede a too rapid fall.

Many Problems To Be Solved.—Space is not available in a treatise of this nature to discuss all of the engineering and mechanical problems that must be solved before the reliable helicopter is finally devised, but some of the most important can be given brief mention. Helicopters have been devised that have ascended vertically and some have maintained their position in the air for as much as an hour. Flights in a horizontal direction have been only a few hundred yards. A helicopter of American design and construction built by Emil Berliner and his son Henry, in Washington, D. C. may be taken as showing how such machines are constructed. It is shown at Fig. 349. It comprises a fuselage similar to that used on airplanes, this having two propellers mounted on outriggers and driven by suitable gearing. The main air screws are 14 feet 10 inches in diameter running at 540 r.p.m. An auxiliary control variable pitch propeller is attached to and above the rear end of the tail, this being 3 feet in diameter running at 1,700 to 1,800 r.p.m. The machine is driven by a 110 horsepower Le Rhone motor and weighs complete with pilot and fuel about 1,400 pounds. Horizontal flights are obtained by tilting the propeller blades to secure thrust on an angle instead of vertically and part of the thrust is thus used to secure forward flight, the remainder and by far the larger portion being used for sustentation. Flights undertaken to date have been at low altitudes ranging from 6 to 20 feet and several hundred yards in a horizontal direction to reduce risk during the experimental period.

The riddle of the helicopter may be considered as comprising four different problems. The first is that of getting off the ground. This is the simplest and easiest part. With modern large propellers a lift of 15 pounds per horsepower can be easily obtained and as aircraft engines weigh around 2 pounds per horsepower, there is ample margin for the weight of the structure, pilot and supplies for a flight of considerable duration. There is no question today that sooner or later a workable helicopter will be built and that it is merely a matter of design, additional information and perhaps a leaven of mechanical genius that are necessary to solve the problem, and the problem itself is big enough to be attractive to men who have already won their spurs in other fields of achievement.

Landing In Event of Engine Failure.—The question of getting safely back to the ground in case of engine failure is much more difficult. An airplane volplanes; the conventional helicopter would drop like a stone. Several unworkable devices have been suggested, such as the use of parachutes, balloons, etc. The most promising suggestions to date appear to

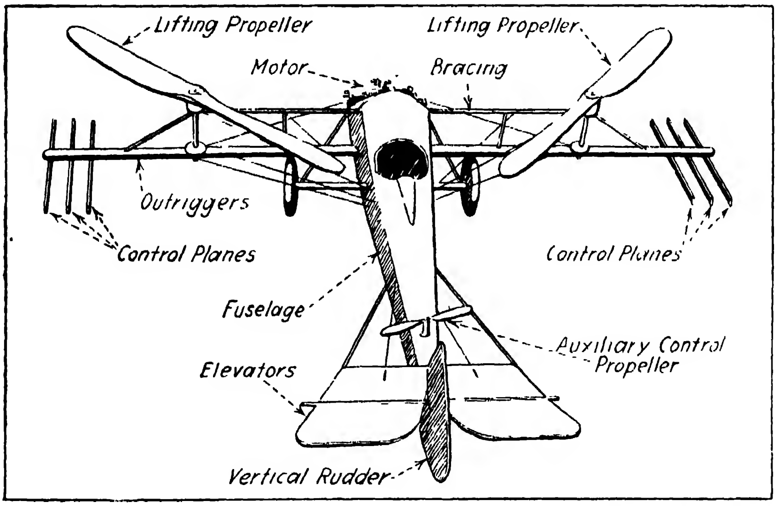


Fig. 349.—View Showing Construction of Experimental Berliner Helicopter. Note Large Size of Lifting Screws.

be the use of propellers with extremely wide blades the angles of which may be changed so that the propeller would spin like a windmill driven by the air pressure during the descent. With propellers of proper size and design the velocity of descent might be considerably retarded, but would still remain too high to be either safe or comfortable. Another proposal involves the use of planes somewhat like those in an aeroplane built up of movable shutters affording large openings during the ascent but acting practically like aeroplanes planes during the descent. Whether such a construction would prove practical with the increased weight and mechanical complications, only time will show.

The next problem is that of keeping the helicopter right side up. In the Berliner helicopter (Fig. 349) control is secured by the use of three movable

fins under each of the propellers, movable about in the stream of air projected by the propeller. The longitudinal control is secured by the little variable pitch propeller shown in the rear of the fuselage of the machine. If the above three problems were properly solved the helicopter would be capable of rising, hovering, and coming down.

To make it a practical transportation device it must also be capable of horizontal travel in any desired direction. This can be obtained either by tilting the whole helicopter so that the propellers pull it both forward and upward (which is accomplished in the Berliner helicopter by the use of the little variable pitch propeller), or by the use of an auxiliary propeller for horizontal drive, or, finally, by varying the pitch of the propellers.

As regards helicopters of which the development has advanced far enough to give a fair idea of their construction, it should be stated at the outset that the information available is somewhat sketchy. The designers of some of the helicopters, for example, Brennan, in England, have absolutely refused to give any information to the public. Others have permitted inspection of their machines and given information but with material reservations.

Helicopters attracted some attention of Austrian army authorities as a means of replacing captive balloons for observation purposes. Helicopters, if properly developed, might prove to be quite valuable for this purpose, since in the first place they offer a much poorer target to enemy fire, and second, have fewer vital points to be hit and are not inflammable. Because of this, during the recent war, Lieutenant Petroczy and Professor Karman were authorized to build captive helicopters, one of which was equipped with electric power and the other with two Le Rhone motors. These are stated to have made flights lasting as long as an hour, being held by a cable and anchorage just as a captive balloon is.

The first problems to be solved are of a purely mechanical character. Variable pitch propellers, method of installing and holding large propellers, layout of the helicopter frame subject to heavy stresses, and yet so different from the aeroplane frame, and the thousand and one details involved in this novel structure will tax the mechanical skill of the designer. As in the case of the aeroplane, this is going to be a matter of slow development, the designers learning by previous failures, and while a great amount of ingenuity will be needed, there does not seem to be anything that would be impossible of solution.

Parachutes, Types and Use.—The parachute is a safety device for operators and passengers of all types of aircraft that corresponds to some extent to the life preserver used in marine service. The need for such a device, in an improved form was seriously felt during the latter part of the World War. Nearly everyone is familiar to some extent with parachutes because for many years, even before the development of the airplane, a feature of country fairs and other celebrations was a balloon ascension with its accompanying parachute drop. The parachute was attached to a ring or crossbar suspended below the balloon and the weight of the aeronaut was carried by a crossbar or trapeze swung from the parachute cords, the entire structure hanging down from the balloon. When the proper height was reached, the aeronaut pulled a cord and cut the parachute and himself

free from the balloon and the parachute filled with air and resisted the fall. Observers in captive balloons could use practically the same type of parachute as carried in a free balloon but this form was not practical for the airplane so the parachute pack was invented and perfected to fill the urgent need for a reliable and practical life saving device for use from disabled aircraft.

Fig. 350.—Two Forms of Parachute Packs Suitable for Airplane Pilots. At Left, Lap Pack Used by Observers and Gunners. At Right, Seat Pack Favored by Pilots.

Requirements of Parachute Equipment.—A popular parachute, known as the Irvin air chute is illustrated at Fig. 350, in its packed condition. The lap pack, shown at the left is used by observers, and machine gunners while the seat pack is favored by many pilots. In addition to these types, there are packs adapted for either the back or the chest. The chief require-

ments for parachute equipment are stated to be as follows by the Irvin Air Chute Company, Inc. of Buffalo, New York:

(1) It must be possible for the aviator to leave the aircraft regardless of position it might be in when disabled.
(2) The operating means must not depend on the aviator falling from the aircraft.
(3) The parachute equipment must be fastened to the body of the aviator at all times while in the aircraft.
(4) The operating means must not be complicated or liable to foul and must not be susceptible to damage through any ordinary service conditions.
(5) The parachute must be of such size and so disposed as to give the maximum comfort to the wearer and permit him to leave the aircraft with the least difficulty or delay.
(6) The parachute must open promptly and must be capable of withstanding the shock incurred by a 200 pound load falling at a speed of 400 miles per hour.
(7) The parachute must be steerable to a reasonable degree.
(8) The harness must be comfortable and very strong and designed so as to transfer the shock of opening in such a manner as to prevent physical injury to the aviator. It must also be sufficiently adjustable to fit the largest and smallest person.
(9) The harness must be so designed as to prevent the aviator from falling out when the parachute opens, regardless of his position in the air, and at the same time it must be possible to quickly remove the harness when landing in the water or in a high wind.
(10) The strength "follow through" must be uniform from the harness to the top of the parachute—bearing in mind the old axiom—"No chain is stronger than its weakest link."
(11) The parachute must be so designed as to be easily repacked with little time and labor.

Approved Types of Parachutes.—The approved types of parachutes are the manually operated, free type. A "free" type parachute is one that is complete in one unit, strapped to the person of the aviator by a suitable harness and one that has no attachments whatever to the aircraft. A "manually" operated parachute is one that will unpack automatically when the wearer gives a slight pull on the ring located in a readily accessible place on the harness. The aviator can open his parachute just when clear of the disabled airplane or he can make a long free drop away from burning wreckage or a pursuing enemy plane before he pulls the ring.

When open, parachutes range from 22 feet in diameter to 28 feet in diameter, the latter being employed for exhibition and training jumps. The usual general service size is 24 feet in diameter. The small one is used in conjunction with the 28 feet diameter for training jumps, being carried as a breast pack. The weight of a complete 24 foot Irvin Air Chute complete with harness is approximately 18 pounds and the average rate of descent is 16 feet per second. The body or air bag of the chute is high

grade silk and suspension or shroud lines are silk cords which are continuous from their point of attachment on one side of the harness to the other, passing through and over the top of the air chute. This form of suspension gives a network of cords which greatly increase the strength. A shock absorbing vent is incorporated in the apex of the silk body. A small parachute known as the "pilot" chute is attached at the peak or apex of the main chute. This is 30 inches in diameter and is constructed with steel ribs and a spring in such a manner that it folds up under tension so it can spring out when the container is opened by the rip cord, catch the air and pull the main chute out into the line of flight. While tests have shown that the pilot chute is not absolutely necessary, it reduces the time required for opening and makes for greater safety at low altitude jumps. The average time required for the air chute to open and assume normal descent is approximately one and three-fifths seconds after the rip cord has been pulled. The back pack, shown at Fig. 352 is recommended for lighter-than-air craft and for exhibition jumps.

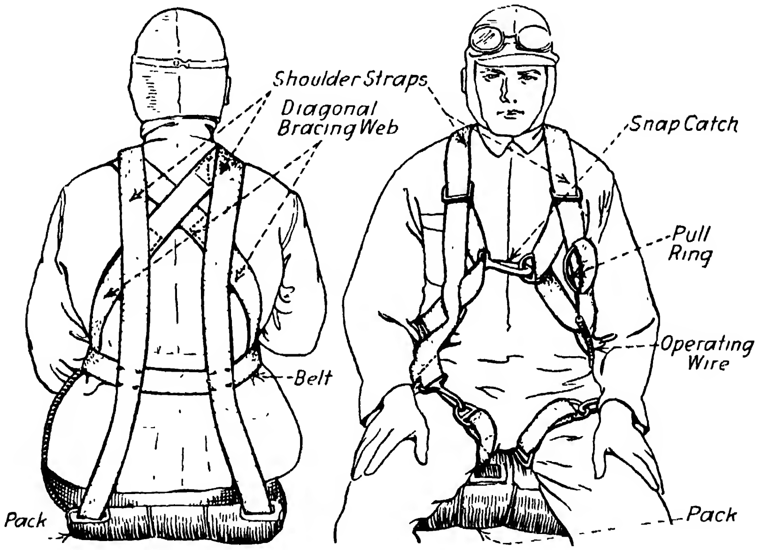


Fig. 351.—Rear and Front Views of Seat Type Parachute Pack Showing Webbing Harness. Note Location of Pull Ring.

Control of Parachutes.—When the parachute has opened the jumper finds himself sitting in what amounts to a swing with webbing representing the ropes of the swing on either side of his body. Slightly above his head and within reach, the webbing divides into two and the shrouds or small cords which lead to the outer edge of the parachute are here attached to the harness in four places. To stop the swaying of the parachute the ropes can be pulled on one side or another. The parachute can be sideslipped about ten feet for every hundred feet of drop by pulling down on one side. The parachute will belly-in on this side, but will open out as soon as the

shrouds are released. The parachute can even be made to spin by pulling down on one side and then releasing the pressure with a sort of flipping motion. This trick is hard to learn and can really only be done by one who had jumped before. In case it is found necessary to swing aside from some building or other obstacle, the shroud lines should be pulled in the direction in which the jumper wishes to travel. The sideslip of ten feet

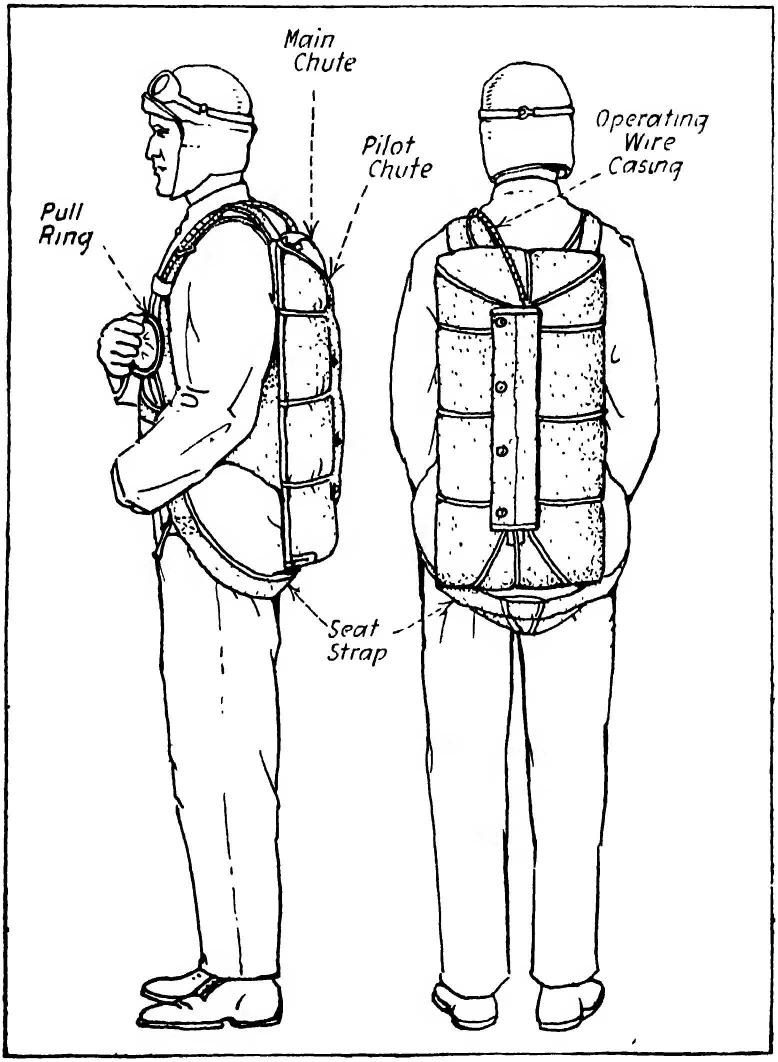


Fig. 352.—Back Pack Used by Balloon Observers and Exhibition Jumpers.

in a fall of one hundred feet is not enough to make headway against any sort of a wind, and this should be remembered in trying to avoid obstacles.

In landing, the feet should be close together and the knees somewhat bent. No effort should be made to stand up and the body should be relaxed. Rolling over absorbs the shock of the fall to some extent, and one is

less apt to be hurt in taking the tumble than in trying too hard to resist one. Some try to roll over backward while others prefer to fall forward in the direction in which they are drifting, but as in most cases the inexperienced jumper has no choice in the matter. Either position, facing or back to the direction of drift will do sufficiently well. Should the jumper see that he is going to land in water, the two hooks across the legs and the hook across the chest can be unfastened so that the aviator can easily get loose from the harness when he alights. The harness of a seat pack is clearly shown at Fig. 351 which shows front and rear views of aviator sitting on the pack.

Maintenance and Use of Parachutes.—The Army Air Corps advocates the packing of a parachute once a month. For commercial purposes this is hardly necessary, and three to four times a year is sufficient. The inspection and repacking takes about one hour with two experienced men and the proper equipment for doing the job. As the correct packing of a parachute is absolutely essential to its proper functioning, the work should only be done by those who know their business thoroughly. The Army Air Corps and the United States Air Mail Service have been glad to cooperate with civilians in the repacking of parachutes. When not in use, the parachutes should be kept in a dry place. When the pack is not going to be used for a couple of weeks it is a good idea to loosen the elastic cords which tend to pull the pack open. When a pack has not been worn for several months it should certainly be repacked, because creases are apt to form in the silk possibly damaging the material. In the event of the pack becoming wet, it should be taken out and dried or else mildew is likely to form. If, however, the parachute is properly cared for and repacked from time to time it will last for several years.

In parachute jumping for exhibition purposes the Army authorities require each man to wear two packs, one on the chest and one on the back, so that if one parachute should break he could pull the string and use the other. The man, when getting ready to jump, stands out on a platform on the strut. Down on the Mexican Border some time ago a man jumped from a 20,000-foot altitude and it took him 17 minutes to reach the ground. One method of leaving an airplane is called "lifting off." There is no jerk; the motion is very easy. It is like jumping from a 10-foot embankment to land in a parachute. The men suffer no injury whatever. One man fell 1,500 feet before he pulled the string. When asked why he delayed so long before pulling the rip cord he said, "Well, I was afraid I would break it." In an exhibition, two men have walked out to the end of an airplane, while in the air, and lifted off together.

Parachute Lands Airplane.—A test made at Los Angeles resulted in a giant parachute bringing a plane and pilot safely to earth from an altitude of 2,500 feet. Upon reaching the desired altitude, R. Carl Oelze, of the Naval Reserve, who piloted the plane, a Curtiss JN, stopped his engine and released the parachute. The plane landed three and a half miles West of the starting place and required 1 minute 6 seconds for the descent, approximately 38 feet per second. The pilot and plane weighed 1,800 pounds The plane was not greatly damaged by the impact, only the landing gear struts and lower longeron being broken, the pilot was not hurt at all. It

is entirely possible that a series of large streamline parachute packs could be incorporated in an airplane so they could be released at different levels by the pilot and enable a safe landing of plane and load.

QUESTIONS FOR REVIEW

1. Name principal forms of seaplanes as distinguished by float arrangement.
2. Why are metal floats superior to wood?
3. Give influence of float design on surface manoeuvering.
4. Describe the U. S. Navy P.N. Series of boat seaplanes.
5. What is an "amphibian" plane and what are its advantages?
6. How does the autogiro airplane differ from the conventional type?
7. Describe a typical helicopter and consider some of the problems of design briefly.
8. Outline features of some very large flying boats.
9. What are the main requirements of seaplanes for naval use?
10. Describe typical parachute packs and how they are attached to aviators.

CHAPTER XVII

SOME ASPECTS OF COMMERCIAL AVIATION

Aviation Immediately after the War—Why Early Airlines did not Pay—Organization Important—Passenger Carrying an Important Field—Mail Transportation Produces Regular Revenue—Commercial Possibilities of Airplanes—Miscellaneous Possible Uses of Airplanes—Navigational Aids Important—Many Types of Aircraft Needed—Fundamental Requirements of Commercial Planes—Planes Must be Kept in the Air—Long Lived Engines Essential—Advantages of all Metal Construction—Earning Capacity of Airplanes—Value of Organization—Maintenance of Flying Equipment—Airways and Airports—Sperry Airway Beacon—Fog-dispersal Experiments—Cost of Air Transport—Figures for a Three-Ship Passenger Airline—P. R. T. Air Service—U. S. Air Mail Figures—How Charges are Based—Location, Cost and Size of Landing Fields—Catapults and Airplane Arresters—Launching by Catapult—High Speeds at High Altitudes—Killing Insect Pests by Airplane.

The most apt definition of a commercial airplane was given by W. B. Stout, a pioneer in the design, construction and application of airplanes to industrial transport when he said: "A commercial airplane is an air vehicle that can support itself in the air financially as well as physically" and if this definition is to be accepted without reservation, then one writing at this time, late in 1927 must concede that we are just on the point of entering the era of commercial aviation. This statement is made with full knowledge of the hundreds of thousands of miles that have been covered by aircraft of various types operating over airlines in all parts of the world since the close of the World War, which has been taken throughout this treatise as the date of starting modern aeronautical progress.

Aviation Immediately After the War.—The cessation of the war left America with a well developed airplane industry that was equipped with numerous factories, well tooled and organized to manufacture military airplanes and engines. Aircraft of all types had accomplished so much in the war that aviation enthusiasts looked forward to a general and wide application of aircraft, especially airplanes and seaplanes, to commercial transport purposes. Unfortunately, few of the airplanes adapted for use of our military services were of any value in industrial applications.

Spasmodic attempts to establish air lines with remodeled and revamped service machines were made, several hundred ex-army and navy aviators purchased wartime surplus airplanes and seaplanes and went around the country "barnstorming" taking people up who wished to experience the novelty of flying but in a few years all this activity languished. In Europe, various airlines were established with the aid of government subsidies and could not have been operated without this financial aid. In this country, no government subsidies were given operating companies, so those who started found that the difference between operating costs and income was too great to permit of profitable operation.

There have been a few notable exceptions as some of the early firms,

profiting from ocasional "taxi" work, photographic and aerial survey, smoke writing, crop dusting and motion picture employment have managed to meet expenses, even though they have not paid large dividends to their owners. The first commercial use of airplanes antedated military use as exhibitions, passenger carrying, civilian racing and prizes, contests brought a spasmodic and limited financial return to early aircraft constructors before the military authorities considered such craft as being at all practical for their use. Before the war, no airlines were operated; no express, mail or passengers were carried on schedule, only as "stunts" for publicity nor were any attempts made to solve practical industrial or transport problems. Few so called "commercial" operators of the early post war period continued in business when the slump came, and the publication of only a few lurid news items in the public press about airplane accidents soon took most of the courage from would be "joyriders" so that element of our population seeking thrills were soon satisfied.

Why Early Airlines Did Not Pay.—Much of the early failure to make air transport pay was due to the use of unsuitable equipment. Even the cheap surplus wartime planes, while they did not require a large immediate investment, called for expensive upkeep. Wartime planes were built primarily for high performance and little thought was expended by their designers of making them either accessible, durable or providing that ease of maintenance that is one of the first requirements of successful industrial transportation vehicles, regardless of the medium on which, or in which they operate. The fundamentals of economics apply just as well to land, water or air vehicles. People engage in business to make money, not as a matter of sentiment and capital must be assured of an adequate return or it will not be interested. It was necessary to evolve and try out entirely new designs of airplanes for commercial use. The high performance and speed of military aircraft could be sacrificed to some extent for reliability and economy of operation. Army authorities estimated that it took at least five men on the ground to keep one man flying and while this proportion could be lessened to some extent in certain classes of work, at the same time, experience with the organization and training of our aviation squadrons and their practical utilization at the front showed that the figure mentioned was reasonably accurate for military flying.

Organization Important.—Just as military aviation squadrons could function efficiently only when properly organized, commercial aviation enterprise must also be intelligently organized if the best results are to be obtained and aviation is to become the commonplace of our everyday activities; as railroads, ships and motor vehicles are. The problem that confronts American business today is: What practical use can be made of airplanes and what will it cost? Since sustained speed is the great advantage of the airplane over other methods of transportation, it is but natural to apply the airplane to tasks that call for the minimum time of accomplishment.

Passenger carrying is thus indicated as one of the first uses to which commercial aircraft may be profitably put. People whose time is the most valuable are those to whom air transport appeals because they are best able to pay for it. Most of our business affairs can best be carried on by per-

sonal contact and while the telephone, mail and telegraph are wonderful aids to modern industry, most important deals are closed only after solicitation and verbal agreement between individuals who are in actual intercourse. Where any great distance separates a busy business executive and his objective, airplane travel may be the most economical means of transport even though it costs more than the usual express train service. When time is money, train or boat or even automobile travel may be too slow.

Passenger Carrying an Important Field.—Passenger carrying airlines are thus seen to be a logical development providing that a reasonable guarantee can be given the prospective passengers that they will be carried comfortably, without mishap and on schedule. In England, various airlines are in operation that have planes that will carry from 10 to 40 passengers, the French Farman Company has developed airplanes that will carry from 12 to 20 or more people. The large Caproni airliners have large capacity and the development of very large seaplanes and flying boats by the Germans, Junkers and Rumpler, Rohrbach and Dornier have been previously mentioned.

Mail Transportation Produces Regular Revenue.—The second commercial use of airplanes and next in importance to passenger carrying is regular mail transportation, fast despatch and financial service. Here the element of personal danger, even though the present percentage is remarkably low, is not as important in limiting aerial service as it is in passenger carrying. The U. S. Post Office Department has carried mail through the air, on both day and night flying routes for the past nine or ten years and it is only recently that it is turning the operation of the air mail over to private contractors.

The third important commercial application of the airplane is in general express transportation, and in the conveyance of expensive or perishable goods and for emergency shipments and in fact any class of goods. the ultimate selling cost of which can bear the extra cost of transportation in exchange for the time saving, can be economically carried by airplane. We find that motion picture films, newspapers, luxury articles, medical and surgical materials, replacements for important damaged machinery such as used in industrial, newspaper or municipal light and water service; jewelry, exotic blooms and numerous other materials might be transported by air and often are.

Commercial Possibilities of Airplanes.—In a paper read before the S. A E. on the "Airplane as a Commercial Possibility" D. W. Douglas, who has been connected with aeronautical activities for a number of years and who is an engineer of international prominence enumerates some of the perishable goods that he believes can bear the expense of airplane transport. He said:

"We may list such things as high-grade certified infants' milk, rare and out of season fruits, vegetables and flowers. The milk for New York City is supplied largely from upstate dairies not having the fastest of rail service. With a preliminary cooling at the dairy this milk could be carried quickly and deposited still cold in the city. Where the breakage of intricate machine parts threatens the tying up of a plant, the aerial express line should find an opportunity to be of value. Shortages in factories work-

ing on a production basis that could ill afford an interruption could be made up from stock in a distant town in the minimum time possible through the air. Occasions arise in epidemics or catastrophes where the shortage of medical and surgical materials, personnel and food becomes serious. With airplanes such supplies could be rushed in the fastest way. Motion picture films could not only be distributed in the shortest time by airplanes, and thus cut down exchange and idle time, but the service would add to the advertising campaign of film companies. News grows stale quickly and small-town papers do not always satisfy the residents of such communities. The faster distribution would increase the out-of-town sales of the daily papers of our large cities and widen the range of their circulation. Articles of luxury which bring high prices in proportion to their weight could in many cases have quicker distribution profitably. Advertisement would enter here to a greater extent than in any other class of service possible. Confectioners and florist in the large cities, enjoying a wide reputation and a high-class trade, could broaden the field of their patronage considerably."

Miscellaneous Possible Uses of Airplanes.—Among the miscellaneous uses that we may hope to put airplanes to, come those of supervision and exploration. While in many of its aspects this work would dovetail with photography, in others ways it presents new fields. Consideration is being given today by the Government to the patroling of the great National Forest reserves by airplanes driven by or carrying an expert forest ranger. A greater check on forest fires could be exerted by this means and in that way much natural wealth conserved More ground can be and is covered with smaller personnel, and reports of fires by wireless from the air to a central receiving station expedites the rushing of fighting crews to the scene of the impending catastrophe.

The inspection and supervision of large properties is made more efficient and rapid by the employment of an airplane by the manager. It is reported that a well known financier has bought a plane and engaged a pilot to aid the manager of some of his large wheat lands in keeping in touch with his work. Policing operations, both state and municipal, could be aided by airplane squads. State constabulary could throw a force of men into an isolated town where a strike or riot impended, by the use of large fast machines kept at central flying grounds. In the exploration of undeveloped country for following waterways or determining suitable water power developments, airplane would provide vision and perspective to the pioneers. For rapid rescue work and transport of relief workers after catastrophies, as the recent Mississippi River valley floods or the Florida hurricanes, airplanes and seaplanes have demonstrated their worth without question.

Advertising literature and descriptive maps of cities, resorts and real estate developments made by the aid of actual aerial photographs would undoubtedly possess enough value to warrant the expenditure necessary to compile them. In surveying undeveloped country for laying new railroad lines through it, the airplane would not only be a valuable adjunct in transporting the surveying parties and supplying them with necessities, but would aid in the making of their contour maps.

Mineral ore, while appearing to be a difficult cargo for seemingly flimsy aircraft to carry, is, in certain localities and in certain grades of ore, a practical load for airplanes. Where mines producing rich ore are located in inaccessible country not tapped by railroads or highways, barring exceptions where the character of the terrain precludes the possibility of landing fields or where altitudes are excessive, an aerial transportation system could be installed without the necessity for heavy investments in roadbeds and grading and could be operated at costs that would not be excessive. If the mine be a small one, removed from the possibility of surface service, the airplane can take out the ore and when the workings are barren leave no great amount of useless investment on the location. In addition to carrying the ore out, labor, equipment and supplies can be brought back on the return trip. Where speed in the operation of a newly found mine and in the marketing of its ore is an advantage, because of high market prices, an aerial system could be put into operation much faster than any surface system and would be delivering the ore months before the road or grading work could be finished.

Navigational Aids Important.—Our navigation means probably call for the most immediate developments. Air compasses now in use are not thoroughly satisfactory at all times and in all weather. Radio direction-finders have been developed and seem to promise a more accurate and dependable method of keeping a true course in flying across country above the clouds or in a rain or fog. Better maps are necessary at once. Present-day maps are usually lacking in true accentuation of natural landmarks such as rivers and mountains. Confusion is caused by the omission of some marks and the inclusion of others when perhaps both look to be of the same magnitude when observed from an altitude of 10,000 feet or more. Cities flown over should be marked in some way to be readily recognizable by night or day.

Means of signalling the location of a field are necessary in a fog. Since most fogs are close to the earth, captive balloons riding above the fog in daytime, or star lights shot above the fog at night, will make it possible for the aviator to find his field. Proper and adequate means of lighting fields for night flying are advisable, since in some kinds of service this will present advantages over day flying.

Radio lighthouses along established routes sending out distinctive signals at regular intervals aid the pilot in checking his position, which may be rendered uncertain by unknown wind conditions and loss of visability of the ground. Landing fields should be provided at reasonable intervals along the course of aerial routes. An endeavor should be made to locate suitable fields as near to town as possible in all cities contemplating airplane service, as a field distant from the center of a town tends to offset the time-saving of aerial travel. The shorter the distance flown the more will be the magnitude of the disadvantage.

Serious contemplation should be given by the proper representative bodies of the State and the Federal Governments to the legal aspect of aerial transportation. Uniform laws governing the behavior of machines in the air and when alighting are needed, as well as inspection regulations to safeguard the public and eliminate ignorant and foolhardy operators.

Proper instruction and examination of pilots are necessary; while the examination should not be so exacting at this time as to be unjust, it should be and can be thorough enough to safeguard against unsuitable and incapable operators.

Many Types of Aircraft Needed.—It seems safe to assume that the uses of aircraft will expand rather than contract. This would indicate that we shall always have as many different sizes of machines and engines as now. Small single-engine planes will continue to attract sportsmen, will be used in special service and even in mail or passenger lines between small towns. Multiple-engine machines, however, possessing, as they do today, the added safety of being able to continue flight when one engine stops, seem certain to come more into use for all regular systems requiring the maximum of safety and dependence. Even though engines develop considerably in reliability, as they must and will, this type of airplane seems bound to predominate from other considerations. The size of the multi-engine machine will therefore probably vary more than at present. Starting with small two-passenger twin-engine airplanes, we shall probably have two, three, four and five-engine planes with horsepowers up to 5,000 and useful loads up to 20 tons, operating in different services in the near future.

As to the speeds that we may expect the machines of the future to attain, it appears that while more efficient machines and engines will undoubtedly increase the maximum possible, many types will be slow. Where a service is operated over country not possessing fast surface transportation, or over broken country and large bodies of water, the slower plane, say that having a maximum speed of about 80 m.p.h., will be the most economical. The attainment of higher speeds will always mean the lowering of the useful load carried. Where there is good rail service, or other conditions call for the maximum speed, we may expect to find planes in operation making with their full load anywhere from 150 to 200 m.p.h. Speed does not mean less dependence or safety but more often surer and safer service. It does, however, except in certain instances, spell higher costs per pound of load carried.

The tendency in engines, as far as their size is concerned, seems still to be toward greater power. What the limit will be is hard to predict, since it is restrained somewhat by developments in other directions. Unless radical changes in the methods now used in the making of air propellers occur, it does not seem that units larger than 1,000 horsepower will be practical. Two or more propellers driven from one power plant by shafting or other means may, however, make it possible to double or treble this figure, lacking any developments in air screw construction.

As to new developments in airplane design, aside from larger or faster machines, it is difficult to see that this will follow any new or startling lines. The problem of descending and arising vertically with heavier-than-air craft, while probably not impossible of solution, seems to present insuperable difficulties. Very likely compromises will be effected which will permit airplanes to land in more restricted fields and in terrain of a rougher character than is now possible.

Fundamental Requirements of Commercial Planes.—The great difference between military and commercial airplanes is in the life expectation

and any craft intended for industry must be more enduring as it will be used much more. Wood, wire and fabric construction that is adequate for military airplanes must be succeeded by all-metal or composite wood and metal structures for commercial use. At the same time, a commercial plane must be kept light and have a higher strength factor to reduce maintenance costs. Mr. W. B. Stout, M. S. A. E. and a pioneer constructor of all-metal airplanes and their application to commercial use, who is responsible for the design of the Ford-Stout three-engine all-metal monoplane shown at Fig. 36 in Chapter 4 has given the subject of commercial planes much study and he has obtained much valuable and practical experience by heading a company operating an airline over which airplanes of his own design and make are flown. He gives the following requirements in the S. A. E. Journal for practical commercial airplanes:

(1) Absolute reliability of structure under all conditions of weather or fire hazard.
(2) Absolute dependability of power plant, accomplished possibly by multiple engines.
(3) A speed of 100 m.p.h., with full load, in horizontal flight at sea level, on not more than 3/5 of the maximum horsepower.
(4) Pilot located forward to assure unobstructed vision when planes become common over air routes, particularly in bad weather.
(5) A pay-load of at least 4 pounds per horsepower, with fuel for 6 hours of flight.
(6) *Ability to operate 20 hours per day in the air with load.*

As these requirements are considered, it will be seen what type of organization would need to be built around such a plane and the types of routes that would be necessary to make it a success.

There are two real fundamental capabilities that a commercial airplane must have: (*a*) the ability to accomplish the most ton-miles per horsepower, and (*b*) the ability to stay in the air the most hours per day. The first includes all of the factors of design that make for performance and which, in most planes, have been made paramount. The second embraces that part of design which relates to cost of maintenance, both in man-hours and in cost of material and overhead. The best commercial plane, therefore, is the one that will accomplish in the air the most ton-miles per dollar per day.

Planes Must Be Kept in the Air.—In assuming, in connection with the plane, a business system and a maintenance and inspection routine that are necessary to obtain the foregoing result, it is seen at once that the business and physical organization surrounding the airplane in its work is next in importance to the airplane itself. A plane cannot perform a maximum number of ton-miles per day unless a traffic department secures business enough to keep the plane full to capacity on every trip. Yet it is of no use to have full loads on every trip unless design, maintenance and inspection have put, and keep, the ship in a condition that will enable it to stay in the air for the length of its prescribed route on every trip that is made.

This last statement indicates, as a side thought, that safety also is a basic condition of airline operation. *If a line is not safe and reliable it certainly cannot earn a dividend,* and any airplane that is not safe under even extreme conditions cannot be called a commercial plane. It is the belief of Mr. Stout that eventually planes must be of metal; that insurance rates will make impossible the use of any other type, particularly for passenger transportation.

Flying equipment standing on the ground is a liability, like a motor truck standing still or an ocean steamship at the dock. It earns its pay by ton-mile service and must be in the air the greatest possible number of hours per day. The airplanes first used in the Air Mail Service have been small and were turned over to the Post Office Department by the Army. Each pilot has had his own plane, therefore, from three to five planes were on the ground for each one in the air. It should not be necessary, in commercial airline work, to have more than one plane on the ground for two in the air, and even this ratio can be bettered. This will be possible, however, only when power plants and other devices are interchangeable, so that operators can change any defective equipment almost immediately and get the machines back into the air promptly. Mr. Stout believes that it is as great a mistake to water-cool an airplane engine for commercial work as it would be to air-cooled a motorboat engine. Better airplane performance with air-cooled engines is only a matter of learning how to reduce the head resistance of air-cooled jobs. Even today, air-cooled engines have proved their superiority for this class of work and, every new airplane projected in American for commercial use with the exception of one, is air-cooled.

Long Lived Engines Essential.—He shares the opinion of other designers that much longer life must be secured between overhauling periods and also believes that the elimination of electrical ignition will greatly increase reliability of new aviation engines. These new engines must have from 300 to 500 hours of life between top overhauls and yet must be so simple and the parts so accessible that two men can overhaul an engine completely over night and have it ready for test flight by morning. With the 18-hour-per-day service that is soon to come in airline work, this will be necessary in order to keep the equipment in the air.

Aviation laws and a sufficiency of landing fields cannot bring commercial aviation until we have commercial planes. Once the right type of machine is available, however, the ground organization becomes of even more importance than the machine. The organization for servicing the planes must concern itself mainly with engines, for the engine is almost the only part that is subject to wear. Systems of engine inspection, replacement, testing, and repair, are too well known to need discussion before automotive engineers, but our increasing experience indicates that the more the power plants can be constructed in a series of complete minor assemblies so that in case of trouble these assemblies can be replaced quickly, the better the design will be. It will not pay to make an airplane engine heavier so that it will have longer life. To add 100 pounds to an engine is to take 200 pounds per day off of the revenue-producing capacity of the plane, which is an amount that will pay considerable ground work and serv-

icing. One-half pound of weight can be saved in the plane for every pound saved in the engine, making a total saving of 1½ pounds, or 30 cents per hour advantage for every pound saved in engine weight. Commercial planes must be able to carry fuel for at least 5 hours for normal work in America, hence low consumption is as important as low engine-weight, because it is necessary to reduce to the minimum the weight of the fuel carried.

Advantages of All-Metal Construction.—Mr. Stout is one of the leading American exponents of all-metal construction and the fact that he was able to convince Mr. Henry Ford that such aircraft were best adapted for commercial work must indicate that he is in possession of facts to support his position that can bear the close scrutiny of one of America's leading business men. He states further:

"Safety is the first requirement for money-making with aircraft. This means safety on the ground, in the air, and under all conditions of wind, weather and vision. It means safety in a crash, if a crash should occur, for the same reason that railroad coaches are made of steel. It means a structure that cannot fail in the worst hurricane, and controllability that will enable the pilot to handle the ship in any storm or wind.

The airplane should have no point of instability, no tendency to stall or to spin, but an ability to fly "hands off" under all conditions, with the engine on or off. It must be able to slow down to less than flying-speed without tending to anything but an even keel. It must come out of a stall by itself without the use of controls, and without falling off on a wing into a spin. Its reliability must ensure it against forced engine-landings and its vision must allow it to continue during the most adverse snow and weather conditions."

Earning Capacity of Airplanes.— Earning capacity is a function of ton-miles in the air. The ship must be designed for an earning capacity that is secondary only to safety. This item involved a survey and study of all operating condition, routes, types of service, cabin capacity, distance range, and the like.

An airplane on the ground is a financial white-elephant. An airplane in the air is a service to mankind. Every minute spent on the ground is entered in the book in red. The ship must operate a minimum of 4 hours a day in the air and eventually will be able to do 20 hours a day. Only on this basis can aircraft pay dividends. The minimum number of hours per day spent in inspection and repairs therefore became imperative, and the type of structure dictated was metal.

Every pound on the airplane is worth 7 cents per hour in the air during a 6 hour day. One hundred pounds of weight saved means $42 a day of increased earnings because of greater load carrying capacity. For the carrying of loads at the highest cruising-speeds no other airplane can compare with the monoplane.

By operating his own airplanes, Mr. Stout can control the safety of operation and the method of handling, so that he can work to a dividend point in strictly commercial operation in the type of carrying that proves to be the most profitable, be it fancy express, mail, or passengers.

Visualize airplanes of this kind leaving Detroit and Chicago every hour.

Ten passengers could be carried on each trip, and $25 per passenger would be a reasonable fare. The trip, including overhead expense, and the like, would cost about $150, leaving a profit per trip of $100. From four to six single trips per day per ship could be made, once full load had been accomplished.

The Air Mail today meets all expenses of its night and day flying from New York City to San Francisco, including the searchlight stations, emergency landing fields, and all the equipment, with a pay-load of 250 pounds. One can see the margin of profit that could be developed in this service with a pay-load of only 1,000 pounds. It has been said by many persons that commercial airplanes cannot pay. As they have been operated in the past, they could not pay, no matter what might be the airplane. Financial success is a matter of management and of working from facts. When we fly at night between civic centers with airplanes that safely carry passengers, freight, collateral, money, antiques, films, and the like, and the ships can remain in the air 20 hours out of every 24, we shall carry passengers cheaper than first-class railroad fare and shall make money by carrying goods at express rates at a profit. It is purely a question of business men putting business fundamentals into airplane operation, a thing as yet undone.

What, actually, do aerial transport services offer to the business world? They will offer the facilities for sending letters and light goods all over the globe at an average speed of 100 miles per hour; a prospect which opens up possibilities so vast that they are simply incalculable from the commercial point of view. When an urgently-consigned letter can be sent direct from London to Sydney in not more than 4 days; when New York is only 33 hours and 20 minutes away from Paris as it was shown to be on those eventful days in May, 1927 by Captain Charles Lindbergh, then the business world will realize what is really meant by the coming of this age of air travel and what benefits it will confer on those who are prompt to take advantage of it. Statistics show that a fatality occurs in the ratio of 1 to every 1,250,000 passenger-miles flown, which would indicate that the odds are 2 to 1 against its occurring in a machine flying 12,000 miles per year for 40 years so the safety of flying should be better appreciated.

Value of Organization.—The ability to make world wide commercial flights and to make them regularly to a time-table has now become entirely a question of minute and very carefully devised organization. Already, though aircraft are still in their infancy, we have machines suitable for our immediate purpose. Already, too, we are well ahead with the work of building up the organization of our airways, with the provision of the emergency alighting grounds, day and night signals and meteorological departments which will be absolutely essential to success if we are to maintain a regular service in bad weather as well as fine. The pilot who flies across country with no land organization to help him may soon find himself in trouble when weather conditions become adverse. But, assuming the existence of the highly organized ground service on which so much will depend, we cannot only warn him of bad weather and direct him into a stratum of the atmosphere where conditions are favorable, but we can also, by directional wireless, keep him on his course when there is mist or fog. Furthermore, by linking up all our main airdromes by a chain of emergency

alighting grounds placed at 10-mile intervals, we can insure that, should he have to descend involuntarily owing to any mechanical breakdown, he will always make a safe landing on a suitable surface.

Organization will enable us, also, to station relief machines along a route so that, should an air mail machine break down and have to make a forced landing on any one of the emergency grounds, another machine could be summoned at once by telephone or wireless, and the mail bags carried on to their destination with nothing more than a few minutes' delay. Organization and precision, the careful guarding against possible mishaps, have given land and sea travel the high factor of general safety which they now possess; and with air travel, granted a sound organization, we see already how we shall be able to secure and maintain as great an all-round safety and dependability as is the case today with train and steamship services.

Maintenance of Flying Equipment.—Maintenance of flying equipment is a most important part of the work of any airline as the morale of pilots and the passenger traffic can be easily ruined because of the thought that something may be at fault with the airplanes used. A force of trained mechanics and careful inspectors have a definite and valuable physcological effect on both pilots and passengers. In the U. S. Air Mail Service, engines were overhauled after 100 hours flying and after six overhauls they are torn down and about 30 per cent of their parts value salvaged and used in building up other engines. During 1925, it was stated that mechanical difficulties caused landings once in each 400 hours of flying though the proportion of forced landings was greater than that in previous years. Thirty per cent of the troubles were ascribed to the water-cooling system, 29 per cent to ignition failure, 11 per cent to carburetion and 8 per cent to lubrication. The remaining 22 per cent were due to failure of mechanical parts comprising the engine itself. The airplanes averaged 800 hours of flying before they were given a major overhaul or rebuilding but the fabric covering of the wings was renewed after about 500 hours flying. Only one airplane structural fault developed in flight in 5 years time, this was the breaking of a control stick fitting where it was welded near the base.

Airways and Airports.—The U. S. Air Mail Service has the best planned and best lighted airways in the world and these have been taken as an example for the construction of airways by other nations. All airways are now directly in charge of the Department of Commerce and an under-secretary looks after all aviation matters. Experience has indicated that airways can be so lighted that safe and regular operation of airplanes at night is assured. An airway provides for transportation at twice the sustained speed of the fastest express trains, yet the cost of the airway is given as only about 10 per cent of what it costs to build a single track railroad of the same length. The following data, furnished by the Air Mail authorities, gives valuable information that can be applied advantageously in laying out future airways for civilian and commercial flying activities.

A typical terminal-field comprises not less than 120 acres and has runways 2,400 feet long in two directions. From the operating viewpoint, it is desirable to have terminal-fields located some distance from large industrial centers because of the smoke and haze that usually hang over such

Fig. 353.—Sperry Revolving Airway Beacon with Automatic Lamp Changing Feature.

centers. This is especially true if night flying operations are contemplated. The Air Mail Service has found that it can carry on night operations under moderately bad fog conditions when smoke and haze are not mixed with the fog.

The terminal-field equipment at Hadley Field, near New Brunswick,

New Jersey, consists of two hangars 85 x 100 feet, with 14-foot clear headroom, concrete floors and walls, wood-truss roofs and doors at both ends. One side-wall is of glass in steel sash; on the opposite side is a lean-to 20 x 100 feet, with 10-foot headroom, which contains offices, shops, stockroom, garages and so on. Hangar floors have a 6-inch slope from the middle of the hangar toward the doors at either end. This allows airplanes to be run out of the hangar readily by one man.

All buildings are flood-lighted, signboard style, to give daylight perspective. A 500,000,000-cp. flood-light is provided for field lighting. The field is outlined with 60-cp. 6.6-volt boundary lights connected on a street-lighting series-curcuit with constant-current transformer. Steel-taped cable is placed under ground to supply the current. An illuminated wind-direction cone is mounted on top of one of the hangars, as is also a 24-inch revolving beacon that guides the pilot to the field. These beacons use a 1,000-watt lamp and revolve six times per minute. The beam is raised 1½ degrees above the horizon. Between New York City and Chicago 70 of these beacons are used.

Accurate weather information is essential for night operations. Thermometers, barometers and anemometers are provided at each terminal-field to assist in judging meteorological conditions; a beacon throwing a sharp beam of light upward at a 45-degree angle is provided to determine the height of clouds at night; field managers, chief mechanics, inspectors and crew chiefs are trained to make meteorological observations.

Each terminal-field has a radio telegraph station and uses it to report weather conditions, departures and arrivals of airplanes, and to give other information to the different terminal-fields and the division office. The radio service is excellent when it works, but when bad storms occur they are usually accompanied by bad static conditions, at which times we use the long-distance telephone. It may be that some day we shall handle our communications as the railroads do, by having a telephone or telegraph wire along the course. The same pole-line might carry current for the beacon lights as they were desired.

No machine-shop equipment is located at any of the operating fields. Bench and hand-tools are provided to the extent of about $450 worth. This is because all major repairs are made by outside firms under contract and no construction work is done by the Air Mail. Operating fields for civilian airlines would require machine shop facilities and wood and metal working machinery depending on the character of the construction work and major repairs to be carried on, because it might be more profitable for a private enterprise to have regular production work for its mechanics to keep employed, a consideration that is not always so important when a government, through the taxpayers, can pay the bills and make up for deficits, that might result from inefficient shop management.

Emergency Landing Fields.—A typical emergency field is comprised of about 45 acres and is about 2,000 feet long and from 800 to 1,000 feet wide, the long way being east and west on account of the prevailing winds in the eastern section of the country. The east and west approaches should be clear, the surface should be solid and it should have the necessary drainage to make landings safe in the wet seasons.

The equipment on an emergency field consists of a 24-inch revolving beacon, mounted on a 50-foot steel windmill tower. Current is supplied by a 1,500-watt farm lighting plant. A shack 12 feet square houses the lighting plant and a telephone. A caretaker is employed and is on duty daily from sundown until sunrise. The emergency fields are outlined with primary-battery boundary lights placed about 300 feet apart. An illuminated wind-direction cone is mounted on the beacon tower.

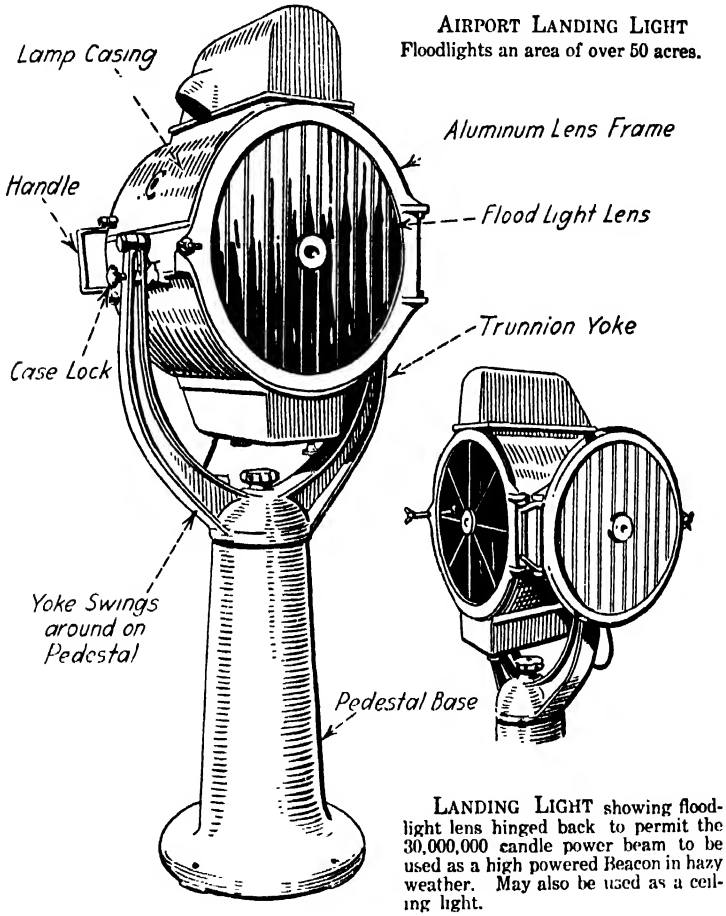


Fig. 354.—Sperry Landing Light for Airports will Floodlight an Area of over 50 Acres.

Fifty emergency fields are located between New York City and Chicago, 36 of which are between New York City and Cleveland, located an average of 13 miles apart across the mountainous and timbered country. Between Cleveland and Chicago, where the country is fairly flat and clear, they are 25 miles apart. It is believed that, with the number of emergency fields we now have on the Eastern Division, the hazard has been removed from

about 95 per cent of the forced landings that may occur on account of mechanical difficulties or bad weather.

Every 100 miles along the airway semi-terminal fields are located. It comprises from 70 to 80 acres, and is a four-way field. Here is carried a stock of gasoline and oil for airplanes that may land and also a small stock of repair parts that may be needed. These fields are equipped with long-distance telephone service and a semaphore arrangement of red, white and green electric lights that are used to signal to the passing pilot what the weather conditions are for the next 100 miles ahead.

Sperry Airway Beacon.—The Sperry revolving incandescent beacon for airways and airports is made in two sizes 18 inches and 24 inches, mounted on the same size base. These beacons are usually mounted on towers of sufficient height so they will be above obstacles that might obstruct the beam. They are visible to pilots from distances of 25 to 80 miles. Incandescent lamps of various voltages may be supplied, though 110 volts is the usual practice where the lamp is supplied from central station and 30 volts if an isolated lighting plant is used, as is often necessary at emergency landing fields. The construction of such a beacon, with automatic lamp changing mechanism in case one lamp should burn out is shown at Fig. 353. The lamp supporting trunnions are rotated by an electric motor through worm gearing housed in the aluminum base of the beacon. The base is water and dirt tight and the lamp drum is completely weather proof. The beam intensity of a 24-inch beacon using a 1,000 watt, 110 volt lamp is 3,000,000 candlepower.

The high intensity airport landing light is normally a flood lighting unit, but in a few seconds it can be converted into a 30,000,000 candle power emergency beacon or it may be used as a ceiling light. This light, which is shown at Fig. 354 is a high intensity arc mounted in an 18 inch cast aluminum drum and is supported by light trunnion arms on a cast aluminum pedestal. The light is obtained from the positive crater of a 80-125 volt, 55 ampere arc. When operated as a projector, the beam has a spread of only 2 degrees but when the spread lens door is swung into place, the beam is spread out horizontally through an angle of 80 degrees but in a vertical plane, the beam spreads only 3 degrees. This fan of light will illuminate an entire field as shown at Fig. 355 which shows how sharply the ground is illuminated in front of one of the Air Mail DH airplanes. The illumination plan for a typical square airport as recommended by the engineers of the Sperry Gyroscope Company is given in the plan at Fig. 356. For a rectangular airport, two landing lights, placed side by side are required to illuminate the area adequately, these being placed near the edge of the field at about the middle so the combined spread of the two beams is 160 degrees, this giving a divergence enough to light a field about 3,000 feet long.

Ground Personnel.—Ground personnel plays the most important part in the operation of airplanes. A thoroughly organized force of trained mechanics under careful supervision is needed to obtain the desired results. A typical Air Mail terminal-field organization for handling of four ships per day is as follows:

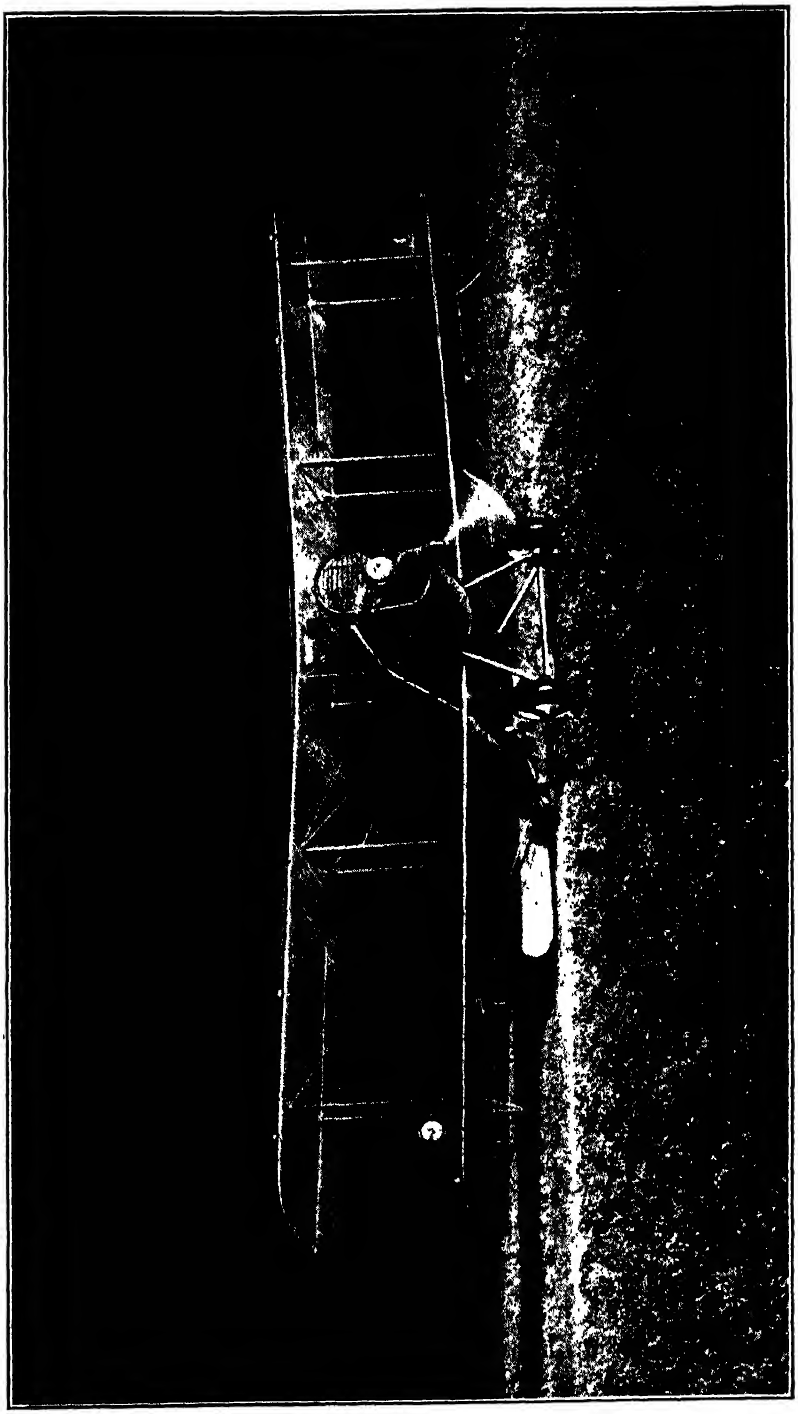


Fig. 355.—Night Photograph Showing Clearly how Sharply an Air Mail Plane and Surroundings are Illuminated by Sperry Flood Light.

Reporting Direct to Field Manager

Chief mechanics	2
Inspectors	2
Field clerks	2
Stock clerks	2
Chauffeur	1
Automobile mechanic	1
Radio operators	3

Reporting to Field Manager through Chief Mechanic

Crew chiefs	2
Mechanics, engine	4
Mechanics, riggers	4
Mechanics, helpers	4
Electricians	2
Instrument man	1
Parachute maintenance man	1

This is the force at the Air Mail terminal-field in Cleveland, where four ships in and four ships out are handled on the day-and-night schedule.

Chief mechanics, crew chiefs and inspectors should be expert mechanics on both airplanes and engines. Engine mechanics and riggers should have at least 3 years' experience. The supply of good airplane and engine mechanics is not keeping up with the demand, as the Air Mail found it necessary to begin training men in the last year. It seems likely that future civilian and commercial activities will have to train a considerable part of their mechanical forces and it must not be expected that the training of a mechanical force and whipping it into a smoothly working organization can be done overnight. An important part of an airway is on the ground and the performance and safety of the pilots are limited by the efficiency of the ground personnel and the ground facilities provided.

As regards spare airplanes, Air Mail practice was one ship on the ground for every ship in the air and a spare engine available for every ship in the air daily. The stock of spare parts carried at the operating fields is very small, as most of the spare parts were assembled in complete flying units, which are always tuned-up and ready to go. For civilian flying, the ratio could be one ship on the ground for each two in the air and with increasing flying time and reliability of engines, it may not be necessary to have a spare power plant for each ship in service, the proper proportion will depend on the type of engine used and its life between overhaulings. If one wishes to be safe, a complete power plant should be in reserve for each airplane in use which means that three spare motors would be provided for each airplane, if this was a tri-motored form and two would be provided for each ship if a twin-motored type.

Fog Dispersal Experiments.—One of the greatest drawbacks to air navigation, just as it is in marine navigation is fog and while it does not always hinder a pilot when he is flying, because he may fly above the fog banks, still it is a menace when landing as if the fog banks are between the aircraft and the ground, the plane must be driven through the fog in making a landing. Experiments are being carried on by the Naval Bureau of Aeronautics in the artificial precipitation of fog over airplane landing fields.

By means of a specially mounted airplane propeller, electrically charged air has been projected in such fashion as to constitute an electrically charged curtain of air which precipitates the fog and thus opens a clear path for landings. These experiments have been carried on at the Naval Aircraft Factory in Philadelphia and elsewhere. Those concerned with the experiments estimate that 277,000,000 cubic feet per minute of fog drifts at the rate of 2 m.p.h. over a landing field through a vertical curtain of charged air having a radius of 1,000 feet with the center on the ground.

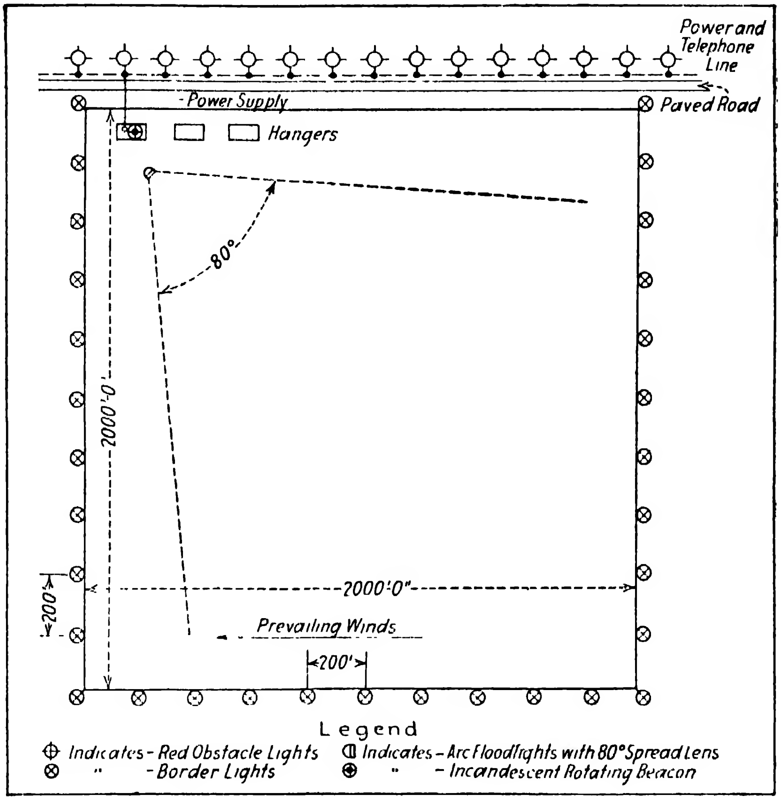


Fig. 356.—Illumination Diagram Recommended by the Sperry Gyroscope Company for Typical Square Airport.

One type of apparatus with which the Navy is experimenting is capable of passing through it 700,000 cubic feet of air a minute, which it charges electrically and throws into charged curtains. It is estimated that these curtains can cause the precipitation of about 95 per cent of the fog moving over the landing field, thus clearing a section 1,000 feet high and 2,000 feet wide over the full length of the field. This apparatus consists of a simple type of corona charging screen, a transformer with rectifying apparatus and an airplane propeller and engine all mounted on a truck. It has been determined that an airplane propeller driven by a 400 horsepower engine mounted on a swivel has sufficient power to project electrically charged air over a vertical plane having a radius of 1,000 feet, thus forming an elec-

trically charged curtain through which all fog coming over the landing field must pass.

Other fog precipitation experiments are being carried on jointly by the Navy Bureau of Aeronautics and the Air Service on the principle of electrically charging dust or sand particles which are released into the fog from airplanes, thus causing condensation and ultimate dispersal of the fog. The successful completion of these important experiments will remove one of the greatest menaces to safe air navigation. The field for the use of fog precipitation apparatus is wide and no doubt ultimately will be used in great cities to lessen traffic congestion and dangers on foggy days, and also in harbors and channels where shipping becomes congested and delayed by reason of fog.

Cost of Air Transport.—There are numerous items entering into the cost of air transport, just as there are in operating a railroad or steamship line. The idea that the layman has in figuring cost of flying by taking the cost of gasoline and oil and dividing it by the number of miles flown on a stated quantity is recognized as an erroneous one by any one with any business experience. The costs are divided into capital charges and operating charges. In the former classification we must group numerous costs. First of all comes organization expense, then cost of furniture and equipment of field and executive offices. Engineering surveys must be made, real estate must be acquired for a main flying field, other property must be bought for terminals and emergency fields. This real estate must be improved as it is doubtful if it can be used without grading, surface water drainage, roads and runways, water supply, sanitary sewerage disposal, etc.

Buildings must be erected to house the personnel and equipment as well as the "flying" stock. These might conceivably include an office building, dwellings for permanent field personnel, shops for wood and metal working, hangars for airplane storage, garages for the auxiliary automobiles and trucks, warehouses for spare parts and supplies and special housing for fuel and oil supplies. The terminals and emergency fields require certain facilities. Lights, heat and power are necessary in all shop and office buildings, telephonic and telegraphic communications, both wireless and wired must be provided. Meteorological instruments, and fire prevention and extinguishing apparatus are essential. Then comes the equipment of airplanes, spare engines, flying and navigating instruments, aircraft radio sets and complete equipment of engine and plane spare parts.

The ground equipment at terminals includes wood and metal working machinery, engine test stands, benches, vises, special trestles and cranes for handling engines, wheeled dollys, gantry cranes for heavy airplane parts, tractors and rollers for field maintenance or for moving the large planes around, automobiles, motorcycles and side cars, trucks or delivery wagons depending upon the nature of the work. These items represent a substantial investment when everything is paid for.

We consider next that large group called operating charges, which are always a matter of vital concern to any executive. The first set of operating charges may be grouped under administration expense. These include

such items as rentals, executive salaries, engineering salaries, clerical and sales department salaries, cost of lawyers, advertising, telephone and telegraph bills, taxes and miscellaneous items such as postage, express and freight, etc. The main items under the heads of operating charges are wages of mechanics, pilots, engineers and other remuneration to officials and clerks, radio men, watchmen necessary to look after and account for the transportation units. There are expendable supplies such as gasoline, oil and grease. Motor transport incidental to operation must be paid for. A large and varied assortment of insurance charges such as fire, accident, property damage, employees liability, personal liability, freight loss, theft, tornado and lightning, etc., must be considered. Then comes that arch destroyer of profits called depreciation. The buildings lose value, the airplanes and engines wear out, accessories and machinery are used up; trucks and automobiles wear out almost as quickly as flying equipment, beacons and radio sets deteriorate with time and use. Heat, power and both shop and beacon lights cost money to keep going.

Telephone and telegraph lines must be maintained. Field regrading is needed from time to time, the buildings must be painted periodically and kept in repair; executives, mechanics and pilots have travelling expenses that must be met. Some of the capital charges can be reduced by using terminal facilities for several airlines just as railroad terminals and docks are sometimes shared by different companies but some of the items must be borne solely by the company responsible for them. All of these items have to be considered in covering charges for carrying merchandise or people. The greatest return can only be obtained by carefully building up the revenue and keeping down operating expenses, which explains why an airplane on the ground is an expense whereas one in flight with a payload is earning. Only the most important items as they occurred to the writer are mentioned in the summary, and other charges may crop up to disturb the managing executive besides those mentioned. The summary is useful in that it may be employed in checking up figures or estimates regarding airline costs that may be made public in the future by over sanguine promoters.

Figures for a Three Ship Passenger Airline.—Some years ago, Mr. D. W. Douglas presented a tabulation in the S. A. E. Journal showing his estimates for a small airline using modified twin-motored military bombers in which Liberty engines were used for power and with a passenger carrying cabin having a capacity of 10 persons, and pilot and mechanic or navigator. He based his figures on an airline operating between points about 100 miles apart and carrying at least 8 passengers per trip, there being twelve trips made each day. Each plane, assuming that two were used and one kept in reserve would make six trips, three going and three returning. Four pilots would be operating every day, each making three flights totaling about 3¾ hours in the air.

The cost given for airplanes and engines, are somewhat in excess of the prices today as tri-motored all-metal airplanes of about the same passenger capacity as those suggested by Mr. Douglas can be purchased for $25,000 each with engines whereas his figure of $40,000 each in following tabulation did not include the engines. Instead of twelve engines, nine

would be sufficient for spares and if one figures these at $3,000 each; a fair price for an air-cooled engine in commercial production, the engine item could be reduced to $27,000 instead of $48,000. Owing to the use of all-metal planes, the cost of the necessary airplane spares would be greatly reduced, a figure of 10 per cent of the value of the planes would be adequate because of reduced upkeep of those modern airplanes in which metal enters largely into the structure. The engine spare parts would not be as high percentage because of the elimination of water-cooling system parts and reduced upkeep of air-cooled engines. A revised figure for the total investment in transportation equipment for an airline having 4 all-metal tri-motored airplanes would be considerably below the figure of $222,800 mentioned by Mr. Douglas and of course, applying to the specific equipment he had in mind when he compiled the figures, some years ago. As the transportation equipment would be renewed every year, a reduction in this important capital charge would correspondingly increase the profit possibilities. At the other hand, the figures given for hangars and shops as well as for machinery and equipment would have to be increased because of higher cost of building construction so the property investment would be greater than his figure.

The reader should bear in mind, when studying the figures given that these were predicated on certain conditions which applied only in that specific airline assumed by Mr. Douglas and that each airline is a separate problem that must be studied by itself. For this reason, the data given can be looked upon merely as an example to show how costs may be figured so that an approximation may be obtained of the capital required and normal operating charges. It is entirely possible that in the light of our present knowledge that Mr. Douglas would prepare an entirely different schedule if confronted with the same problem today. For instance, the cost per passenger mile in the example given is eighteen cents. Even at that time Mr. Douglas estimated that with larger and faster airplanes than were then immediately available that passengers could be carried at a good profit as low as ten cents per passenger mile. While the figures below show a percentage of profit of 30 per cent on the investment, the estimated earnings might be greatly reduced by conditions which would prevent plane operation and weather unfavorable to flying might greatly reduce the number of passengers carried. Instead of the figure being 80 per cent of maximum capacity, it might be reduced to 60 per cent of maximum capacity due to cancelled trips or lack of patronage. It would seem, therefore, that any airline to be profitable should not depend only on one class of traffic. Express and mail matter should be carried as well as passengers so that even if weather conditions deterred passengers from flying, but could be overcome by an experienced pilot, the planes could be kept in the air, trips made on schedule and each trip made to produce some revenue. The U. S. Air Mail has operated with an efficiency as high as 97 per cent and with the experience gained in this service, and with properly lighted airways, a flying schedule could be maintained nearly at normal even if weather conditions were not always ideal; or if the number of passengers did not reach an expected total.

EXAMPLE SHOWING AIRLINE COSTS AND CAPITAL REQUIRED

Capital and Invested Expenses

Property and Equipment Investment

Docks, hangars and repair shops	$ 60,000	
Machine tool and hangar equipment	35,000	
Office equipment	4,000	
Gasoline tank equipment	3,000	
Total Property Investment		$102,000

Transportation Equipment per Year

3 Airplanes, without engines, @ $40,000	$120,000	
12 Engines @ $4,000	48,000	
Airplane spare parts (15 per cent of value of planes)	18,000	
Engine spare parts (60 per cent of value of engines)	26,800	
Material	10,000	
Total Annual Equipment Investment		222,800

Direct Operating Cost per Year

Gasoline: 210,600 gal. @ 20c	$ 42,140	
Oil: 8,100 gal. @ 70c	5,670	
Total Annual Operating Cost		47,810

Annual Salaries for Personnel

1 Chief pilot and general manager	$ 7,500	
6 Pilots @ $4,000	24,000	
6 Flying mechanics @ $2,500	15,000	
2 Shop superintendents @ $3,000	6,000	
1 Passenger and purchasing agent	4,000	
1 Auditor	3,600	
2 Ticket agents @ $1,300	2,600	
2 Draftsmen @ $2,000	4,000	
16 Field mechanics @ $1,560	24,960	
40 Shop mechanics @ $1,300	52,000	
2 Watchmen @ $1,300	2,600	
3 Stenographers @ $1,300	3,900	
Total Annual Payroll		150,160

Overhead

Building and dock upkeep	$ 4,000	
Fire insurance on building and equipment	600	
Taxes	4,500	
Heat, light and power	3,500	
Office supplies	1,500	
Postage, telegraph and telephone	3,600	
Depreciation of building at 5 per cent	3,000	
Depreciation of machine tools and equipment at 10 per cent	3,500	
Depreciation of office equipment @ 10 per cent	400	
Depreciation of gasoline storage tanks @ 10 per cent	200	
Total Overhead		24,800

Cost of Operation per Year

Transportation equipment	$222,800	
Materials	47,810	
Salaries	150,160	
Overhead	24,800	
Reserve for unforeseen expenses	20,000	
Total Annual Operating Expenses		465,570
Passengers carried per day (80 per cent of maximum)	96	
Passengers carried per year (80 per cent of maximum)	25,920	
Cost of trip per passenger	$18	
Cost per passenger mile	$0.18	
Gross receipts @ $22 per trip	$570,000	
Total profit	$104,430	

Investment Required

Transportation equipment	$222,800	
Property and equipment	102,000	
Working capital required	25,000	
Total Investment		349,800

P. R. T. Air Service.—On Tuesday, November 30th, 1926, the Philadelphia Rapid Transit Air Service, which was inaugurated as a feature of the Sesqui-Centennial Exposition, closed a very interesting and instructive experiment in commercial aviation. While the service was carried on for a relatively short period of five months as it closed when the Exposition closed, some very interesting figures were obtained and much information and instructive data was transmitted to the Air Secretary of the Department of Commerce for the guidance of people intending to start airlines.

By actual count 3,695 passengers were carried between July 5th and November 30th in perfect safety. 93,770 miles were covered in regular service without any mechanical failure whatsoever, either in the planes or in the engines. Out of a total of 688 trips scheduled, the only ones not carried out were the 75 cancelled because of extremely adverse weather conditions. In other words, about eleven per cent of the scheduled trips were cancelled because of the keen regard of the P. R. T. Air Service for their passengers' safety, and not because the cancellation was actually forced on them. Government radio and weather-report service would eliminate the necessity for such cancellations almost entirely.

The three big Fokker tri-motor planes have spent 1,184 hours in the air on regular scheduled trips and no appreciable deterioration of the airplane structure in that time. The 12 Wright "Whirlwind" engines have piled up the total of 3,552 engine hours without giving the slightest trouble, and with a total cost of $75.53 for replacement parts, or an average of less than $6.30 per engine—$1.26 per engine per month—$0.021 per engine per hour! The excellent record of gas and oil consumption kept by the P. R. T. reveals that each plane used an average of 10.6 gallons of fuel per engine per hour, and an average of 1/5 gallon of oil per engine per hour.

Many remarkable results were achieved by the P. R. T. Air Service during their five months of operation. For example, a regular schedule was maintained with almost clock-like precision, leaving Philadelphia south-

bound at 8:30 a. m., 10:15 a. m. and 3:30 p. m. and arriving at Washington at 10:00 a. m., 11:45 a. m. and 5:00 p. m., respectively. The 8:30 a. m., plane went on to Norfolk, arriving at noon. On the northbound schedule, this plane left Norfolk daily at 1:30 p. m., arriving in Washington at 3:15 p. m., and at Philadelphia at 5:00 p. m. The other two planes left Washington 8:45 a. m. and 2:00 p. m., arriving at Philadelphia at 10:15 a. m. and 3:30 p. m., respectively. The planes were generally booked to their full capacity of eight passengers, and reservations were carried many weeks in advance. Complete de luxe bus service carried passengers to and from the planes at Philadelphia, Washington and Norfolk, and excellent waiting rooms were provided at the landing fields. Express was actually carried from door to door at a rate of 25 cents per pound with free collection and delivery service within the limits of each city. The management of this air-line found that passenger and freight transport revenue paid about 50 per cent of the operating expenses, so in order to have made the line profitable, mail matter should have been carried to provide the additional required revenue.

U. S. Air Mail Figures.—The Air Mail figures for a period when 198,262 miles were flown in one month gives the direct cost of transportation per mile as approximately 23 cents but the amount expended for each mile flown was $1.36. This means that for every hundred miles of flying, $136.00 was spent, of which only $23.00 was direct cost figuring pilots pay and expense accounts, gasoline, oil and forced landings. The power used in a U. S. Mail plane could easily transport six people at the same speed as the mail is carried or about 120 miles per hour and could undoubtedly carry ten passengers in an airplane designed to fly at 90 miles per hour. This means that the fare to be charged per passenger, to make the line self-supporting would be $13.60 per 100 miles. A private operator would require a profit over the costs, so if he charged $15.00 per passenger for the 100 mile trip he would have $2.40 profit per passenger or about 16 per cent gross profit. Of the total expenditure per mile, the figures for the month indicated that about 24 per cent was spent for maintenance of way, 22 per cent was spent for maintenance of equipment; about 17 per cent represented direct transportation cost, 6 per cent was expended for executive overhead and the balance or slightly over 30 per cent was chargeable to the capital account. The usual "taxi" charge for carrying passengers in a small plane is about $30 per hour. If two passengers are carried, it will cost them each $15 to fly about 100 miles. The same distance by train would cost them each from $4 to $6. In an airplane the 100 mile trip would be made in an hour, by rail the trip would take 2½ to 3½ hours.

How Charges Are Based.—If one bases his figures on the Air Mail, as a general basis for calculation, the commercial operator can figure his costs of flying at from ten cent to fifteen cents per passenger mile with airplanes of reasonable capacity. If ten passengers weigh 1,500 pounds, or an average of 150 pounds per person, then a plane capable of carrying that live load could transport about 2,000 pounds at somewhat lower speed and still maintain a 3 to 1 ratio or better over rail transport. If it costs $136 to carry ten people 100 miles, it will cost about the same amount to carry one ton of freight or express which indicates that a pound of such material can be carried by air 100 miles for about seven cents, so if any profit is to be counted on the rate would be about $10 per 100 pounds per 100 miles.

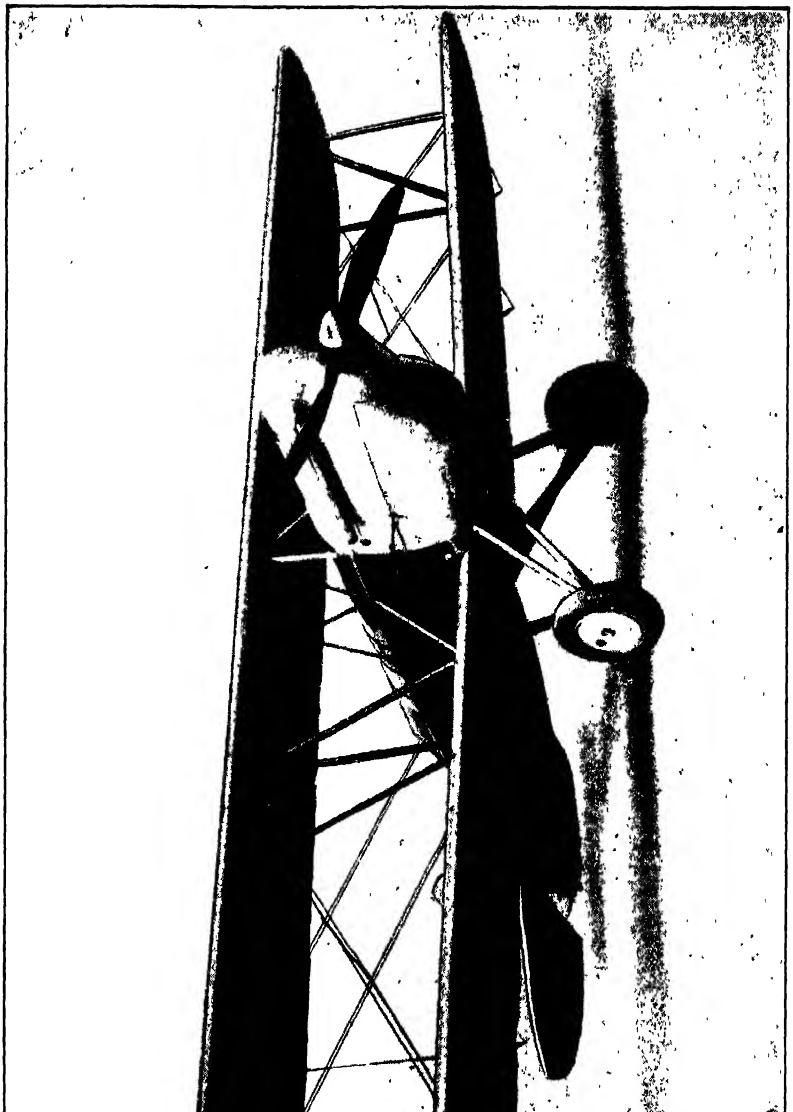


Fig. 357.—Boeing Tractor Biplane Designed for Air Mail Service.

The experience of French and English airplane operating companies bears out cost estimates as given above as without considering capital charges or profits the cost per airplane mile runs about $1.10. A profitable airplane route carrying passengers, mail or freight should figure on a revenue of about $2 per airplane mile because the operating cost, including capital charges will run at figures ranging from $1.25 to $1.50 per airplane mile considering only normal maintenance. Some allowance must be made to cover unusual depreciation and "washouts" due to accidents, also such items as income taxes and capital surplus. The cost of flying sport planes will run from 30 cents to 50 cents per airplane mile, depending on the initial investment and the amount of outside assistance needed to maintain the airplane. In army circles over ten years ago we used to estimate our costs of flying training ships at about $1.00 per airplane mile, a figure which modern experience indicates is not very far from the average for a 100 horsepower 2 or 3 place biplane of wood and fabric construction.

Why Various Estimates Conflict.—There have been many conflicting estimates given of airplane operating costs when these have been applied to commercial uses, and the reason for this conflict between authorities is the numerous factors that determine the initial investment required and the operating and fixed charges. Then again, there has been no uniform system of accounting and variations in this practice will make considerable differences in final figures because of the apportioning of various charges to different accounts. These factors are numerous and diversified. Among those that will have a vital influence are the following: Volume of traffic and amount of work done by each plane. The size of the planes and amount of paying or revenue producing load carried per horsepower. The amount of revenue producing load carried each trip is important, as "ferry" work, which means trips without revenue producing loads or the mere transport of the airplane from one terminal to another, costs money without producing a corresponding income. As a further consideration, one must determine if a close adherence to schedule will be necessary, whether routes are over land or water or both, which will dictate the type of aircraft to be used and if the bulk of the flying is to be done by day or night.

The capital investment will be constrolled by the extent of local or government cooperation and assistance and if existing terminal facilities will be adequate or if new fields and terminals must be acquired. Another important factor is that of airplane and engine maintenance, which is based primarily on the experience and efficiency of the management and personnel. The cost of securing business and the cost and ability of labor used in operations, the experience and pay of pilots, the operating difficulties or natural hazards and the cost of supplies all must enter into the computations. Figures that are correct for one set of facts can often be made ridiculous by presentation of another set of facts. Even on lines using the same number and type of airplanes and engines, and flying the same distance per trip operating costs may be higher on one than the other because the equipment is used more on the line having the lower cost and the factors of increased volume of traffic and greater intensity in the utilization of equipment has resulted in a greater revenue and a greater spreading out of operating and capital charges. A cold-blooded analysis by com-

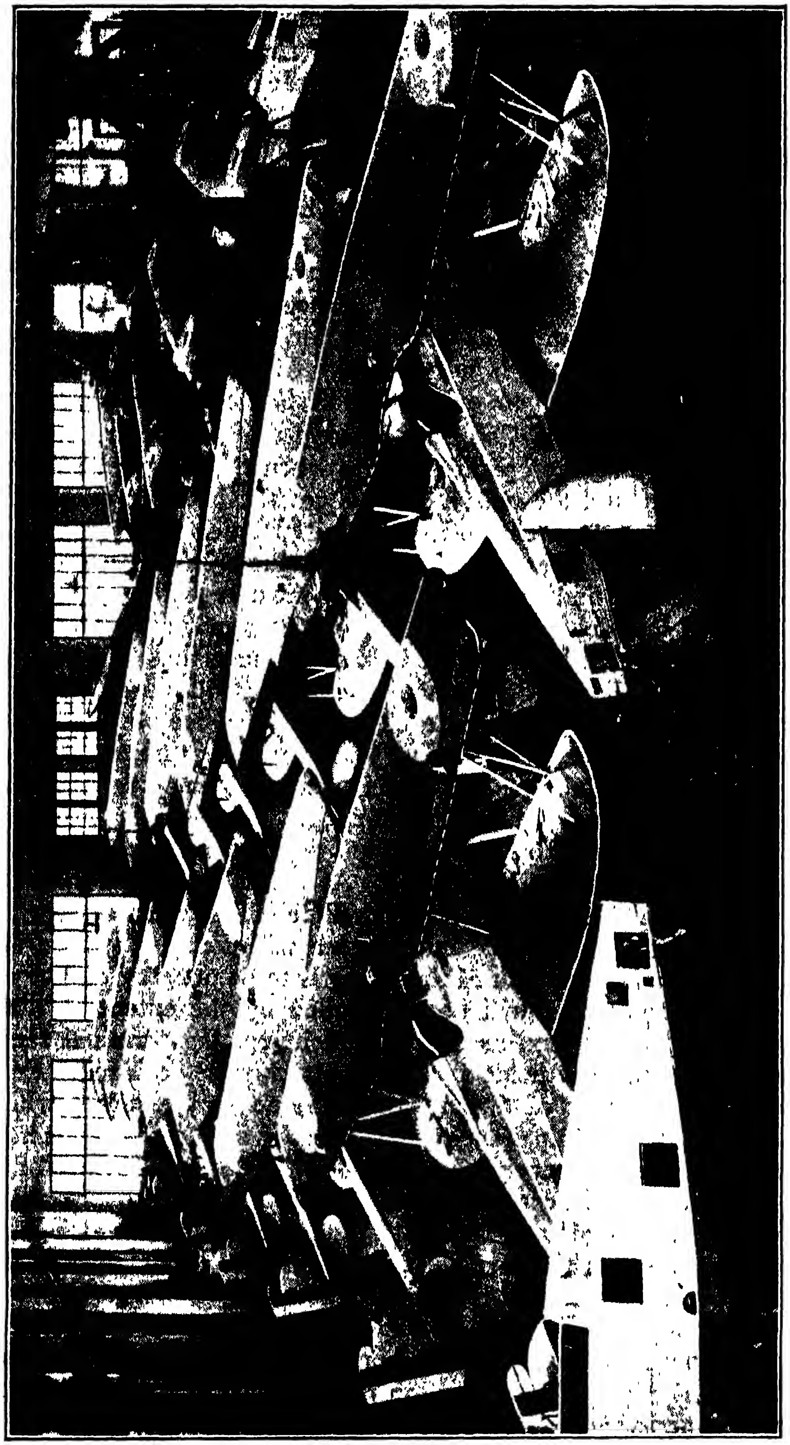


Fig. 358.—Final Assembly Floor of the Boeing Airplane Factory Showing Quantity Production of Biplanes.

petent engineers must be made before any airline is projected or capital is invested in such projects.

Location, Cost and Size of Landing Fields.—A field, with runways at least 2,000 feet long in two directions at right angles, recommended by the Joint Committee on Civil Aviation of the United States Department of Commerce and the American Engineering Council. The Chief of the Air Mail Service states that a field should be approximately 2,000 feet square and that no obstructions should exist within 1,500 feet of the field boundary. The usual length of run for an air mail plane in still air is 1,000 feet for taking off and 1,500 feet for landing. The distance given for landing can be cut in half by the use of wheel brakes. The taking off run cannot be changed materially. The emergency fields on the transcontinental air mail route are selected to give East and West runways of 2,000 feet long and at least 900 feet wide, with clear approaches.

The investment in a landing field varies between wide limits. Land, in general, is leased. Municipal fields at St. Joseph, Mo.; St. Louis, Mo.; Cleveland, Ohio; and Hartford, Conn.; where the land has been purchased, show an average cost of $522 per acre and an average size of 120 acres. Cleveland appropriated $1,250,000 to buy and condition the Cleveland airport. The average price for the land under the city options was approximately $1,000 per acre. Land adjacent has recently been appraised at from $1,500 to $1,800 per acre. The cost of preparing the surface of the field also varies widely. Boston has spent over $50,000 for this item; Cleveland, $72,000; Hartford, $10,000; Baltimore, $1,200; St. Joseph, $4,000 and Iowa City, $1,000. Complete lighting of a field for night flying, with a flood light, revolving beacon and boundary lights to mark the field outline, may cost up to $10,000.

The distance of the field from the center of the city varies with the size of the city, the greater distances going with the larger cities. The following table from "Aviation" gives the characteristics of the principal fields used by the Air Mail Service in respect to size, distance from the post office and the time usually taken to transport mail by truck from the field to the post office:

Field	Size (ft.)	Distance from Post Office (Miles)	Time of trip of truck (approx.)
New York, N. Y. Hadley Field, New Brunswick, N. J.	1800x2200	31 1	90 min.
Bellefonte, Pa.	1635x2276	3	20 min.
Cleveland, Ohio	3300x2700	10	40 min.
Bryan, Ohio	1877x1944	1	10 min.
Chicago, Ill. (Maywood)	2500x2500	12 67	60 min.
Iowa City, Ia.	2500x1800	2.5	20 min.
Omaha, Neb.	2000x2000	8	45 min.
North Platte, Neb.	2600x3000	4	25 min.
Cheyenne, Wyo.	2100x1800	2	10 min.
Rock Springs, Wyo.	2000x1500	4	30 min.
Salt Lake City, Utah	2000x1000	5	20 min.
Elko, Nevada	2600x2600	1	10 min.
Reno, Nevada	2200x2200	3	20 min.
Sacramento, Calif.	6400x4300	11.75	45 min.
Concord, Calif.	1500x1300	2	20 min.
San Francisco, Calif.	1200x600	4	35 min.

Catapults and Airplane Arresters.—One of the drawbacks to commercial aviation, in the minds of some people, is that flying terminals must be and usually are located at some distance from the city they serve, largely because a sufficient area of land can be secured only at some distance from center of civic activities. As ordinary means of transportation must be used from the airport to the city, considerable time gained in the air is lost at the terminal. If means are devised to permit airplanes to land and take-off from limited areas, it might be possible to have landing areas right in the heart of large cities, the platform being supported by or acting as the roof of a number of large buildings. Aircraft carriers for naval use have special decks for landing if land machines are used, and catapults are utilized to launch the airplane, which may be either of the land or seaplane type or a combination of the two. It has been suggested that when a landing platform is erected in a large city that it cannot have the area provided for a flying field outside of city limits. A platform 1,000 feet square would be a very small landing field and as it would be five city blocks long and five city blocks wide, assuming 200 feet for each block, it will be apparent that structural problems of such magnitude would be involved that their solution would be rather difficult, though by no means impossible.

The Langley, a pioneer American aircraft carrier has a deck 65 feet wide and 503 feet long. As this is a mobile platform that can be headed into the wind, it will be apparent that modern land planes equipped with wheel brakes can land without relying entirely upon the arresting gear. A landing platform over the roofs of buildings should be at least 600 feet square because the winds vary in direction and enough space must be provided so the plane can land headed into the wind which may be coming from any point of the compass. On the Langley, the arresting gear is on the aft part of the deck and covers about one-third its length. It consists of ropes and nets attached to sand bags so the plane running gear is retarded as soon as the arresting gear is reached by the braking effect of the sand bags dragged along the deck and the load can be progressively applied and augmented because more sand bags will be dragged along as the plane loses momentum.

The gear used by the United States Navy at the present date does not take up so much room that it could not be mounted on the roofs of several large sized office buildings and successfully operated. The Loening Amphibian, an airplane weighing 3,300 pounds empty, carrying a useful load of 2,200 pounds and with a high speed of 122 m.p.h., was recently launched by catapult in a distance of 50 feet. It is understood that scout planes of the Vought type are arrested in from 40 to 50 feet on the U.S.S. Langley. The problem of landing on a stable surface would be much simpler than making contact with the deck of an airplane carrier at even stalling speed if the vessel was pitching due to rough water. It has been stated that successful landings have been made on the deck of the U.S.S. Langley with the stern of the vessel having a travel of 30 feet in a vertical direction. If the plane fails to engage the arrester, the landing platform would offer no obstruction to continued flight. The shortest distance in which a good landing can be made by a skilled pilot is about 200 feet by making a "stall"

landing, so as platform 600 feet square would be ample if provided with arresting gear and launching catapults for present day airplanes.

Other uses for arresters and catapults seem to be further in the future and their mention is not to be taken as a forecast. Airplane service to and from ships on the high seas would be a convenience, although probably costly. It is also possible that landing platforms may be anchored in a chain across the Atlantic to provide for transatlantic flight. Such platforms can be built with horizontal vanes or surfaces below the depth of wave action and, thereby, rendered practically stable and they can be double decked, the top deck being used for landings and the space between decks for equipment, supplies and plane storage.

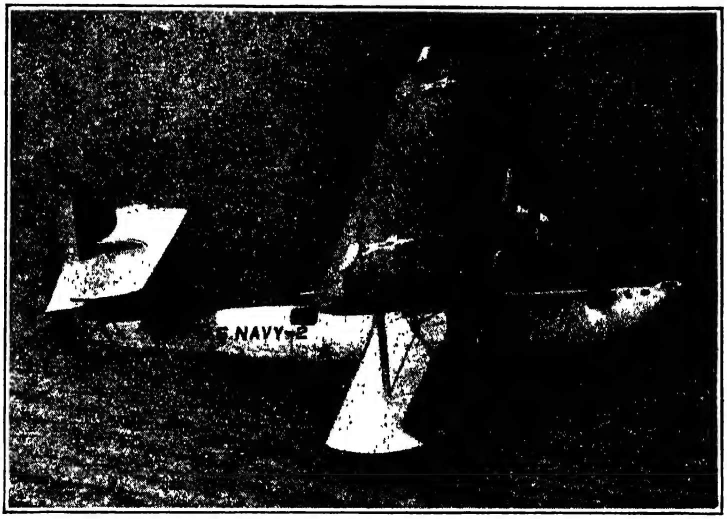


Fig. 359.—Boeing-Navy Tandem Motored Boat Seaplane in Flight. Water Provides Excellent Alighting Facilities for Aircraft Equipped with Suitable Floats.

It should be remembered that, while exceptionally long non-stop flights may be made, the profitable operation of commercial airplanes is limited to relatively short non-stop flights, since the great weight of fuel necessary for a long non-stop flight decreases the possible pay-load to an unprofitable extent. At present this limiting distance is in the neighborhood of five hundred miles. It may, of course, be possible to refuel while in flight, but it seems more likely that if the Atlantic, or other oceans, are eventually crossed by commercial airplane routes, some provision for landing at intermediate stations will be made.

Launching by Catapult.—When launching by catapult, the airplane must be brought from at-rest up to a speed of 50 m.p.h. in a run of less than 50 feet. This requires an acceleration of 2.5 g, where g is the acceleration of gravity, and reinforcement of the airplanes to withstand this thrust. The primary conditions are that the airplane must be made fast to the launching-car, so that it will not nose over while the engine is being warmed-up. Throughout the accelerated run it must be held fast to the car,

so that the rolling of the ship and side winds will not cause the airplane to leave the car and also that, because the center of gravity is well above the deck of the car, the acceleration imposed will not cause the airplane to turn over backward.

The launching procedure is about as follows: The airplane is secured to the launching-car, which is latched at the head of the run, the air-flasks are charged to suit the conditions of launching and the engine is warmed-up. When everything is ready, the catapult is trained into the relative wind are nearly as possible. When the pilot is satisfied with the conditions, he gives a signal, the catapult valve is thrown to the operating position and the car is released. It proceeds down the track under acceleration provided by the catapult engine until the car is about 1 foot from the car-arresting device. At this point, the air pressure is released and the car and the airplane proceed together until the car hits the arresting device; then, the car being retarded, the airplane forges ahead, releases itself from the car and proceeds on its flight. The latest development, is a powder catapult in which a powder charge is used instead of compressed air. This has been very successful, and the problem of controlled acceleration has been solved. The first launching was accomplished in 0.9 seconds in a 30 foot run, though from 1.5 to 2.0 seconds is used at present depending on the amount of head wind and the weight of the plane being launched. At first the car which carries the airplane was shot overboard, though it was recognized that this would not do in service. The problem of stopping the car was solved eventually, but it was not an easy one because forces in the nature of 20 *g* have to be handled, so as to reduce the distance for stopping the car to the minimum, and the car weight must not be excessive. Up to this year, compressed air has been used for the purpose and the problems involved are thoroughly understood and solved. Launching by catapult was the system used in early Wright and Langley airplanes but the U. S. Navy device is a big step forward from the simple falling weight used by the Wright Brothers and previously described.

High Speeds at High Altitudes.—A possible future development in passenger transport with airplanes is the use of high flying craft for passenger carrying on a commercial scale. For long distance flights, aeronautical and meteorological authorities seem agreed that better and more uniform weather, favoring winds and greater speed can be obtained at altitudes in excess of present day airplane ceilings. While there are many problems that will require solution before commercial flights at a distance of from 8 to 10 miles above the earth's surface will be practical, there is no reason to believe that they will remain unsolved and it is entirely within the realms of probabilities as well as possibilities that the next generation may be transported at speeds up to 300 miles per hour at high altitudes because racing airplanes have made better speeds than 250 miles per hour a few thousand feet above sea level only recently. A writer in Aviation discusses some of the problems and suggests lines along which their solution may be attempted in an interesting manner as follows:

"Flying at 50,000 feet, an air tight cabin with normal ground atmospheric pressure inside would have to withstand a bursting force of 13.01 pounds per square inch. By making a cylindrical cabin of a diameter of

8 feet, with semi-spherical ends, so that all parts were in tension, a safety factor of four could be obtained by using sheet duralumin of a thickness of .0694 inch. As such thicknesses are common practice in flying boat hull construction, it is fairly obvious that weight would not be prohibitive. By using a wind driven air pump, normal pressure could be maintained in the cabin and fresh air supplied. Temperatures at 50,000 feet, vary from about 130 degrees fahrenheit, at the equator to—70 degrees fahrenheit, in the temperate zones. The compressed air from the supercharger would be heated and, with the exhaust heat and insulation possibilities, the cabin could easily be kept warm.

At 50,000 feet, the air has about 1/6 the ground density, and the plane would have to travel at 2.56 times ground speed to maintain itself in the air. Although the lift/drag ratio remains the same, the plane would have to travel forward 2.56 times as far in a given time to stay in the air and, thus, would require 2.56 times the power necessary to keep it in the air at ground level. However, to attain the same high speed at ground level would require about fifteen times the power. The power loading would, of necessity, be very low, a fact which is probably the most serious problem from the commercial standpoint, as it limits both the length of the flight and the useful load.

The most difficult problem next to that of sustentation to be solved is getting and delivering the power at these altitudes. Fortunately for the advancement of aviation, McCook Field has been doing an immense amount of work along these lines. The supercharger has been developed to a point where it ceases to be fantastic to claim that full power will ultimately be developed at 50,000 feet. McCook Field engineers have built propellers of great diameter and area, they have built variable pitch propellers and, perhaps equally important, they have built and applied to airplanes a change gear mechanism so that a geared propeller can become a direct drive propeller.

Little is known about wind condition at very great heights, but, from existing knowledge, it can safely be said that, between 30,000 feet and 60,000 feet, favorable or neutral winds can be found if the course can be varied from southern to northern routes. In the region of the trade winds, for example, five different general layers of wind direction have been noted. These altitude winds are much more regular than the surface winds, and their velocity is higher though not as high as popularly supposed."

Killing Insect Pests by Airplane.—Considerable success has attended the experiments of the United States Department of Agriculture in the use of the airplane as a means of distributing poison dust over both treeless and wooded swampy areas for control of malaria mosquitoes. In the final tests, more than 99 per cent of the larvae in the area treated were destroyed with one application. In developing the method of handling the planes so as to distribute the dust properly and in determining the quantity of Paris Green to use, flights were made first over open fields, then over dry woods, and, finally, over various types of mosquito-breeding swamp and lake areas. With an experienced pilot, and when careful attention was given to the spread of the dust, no special difficulty was encountered in distributing it over the treeless parts of the lakes. Furthermore, from a single experi-

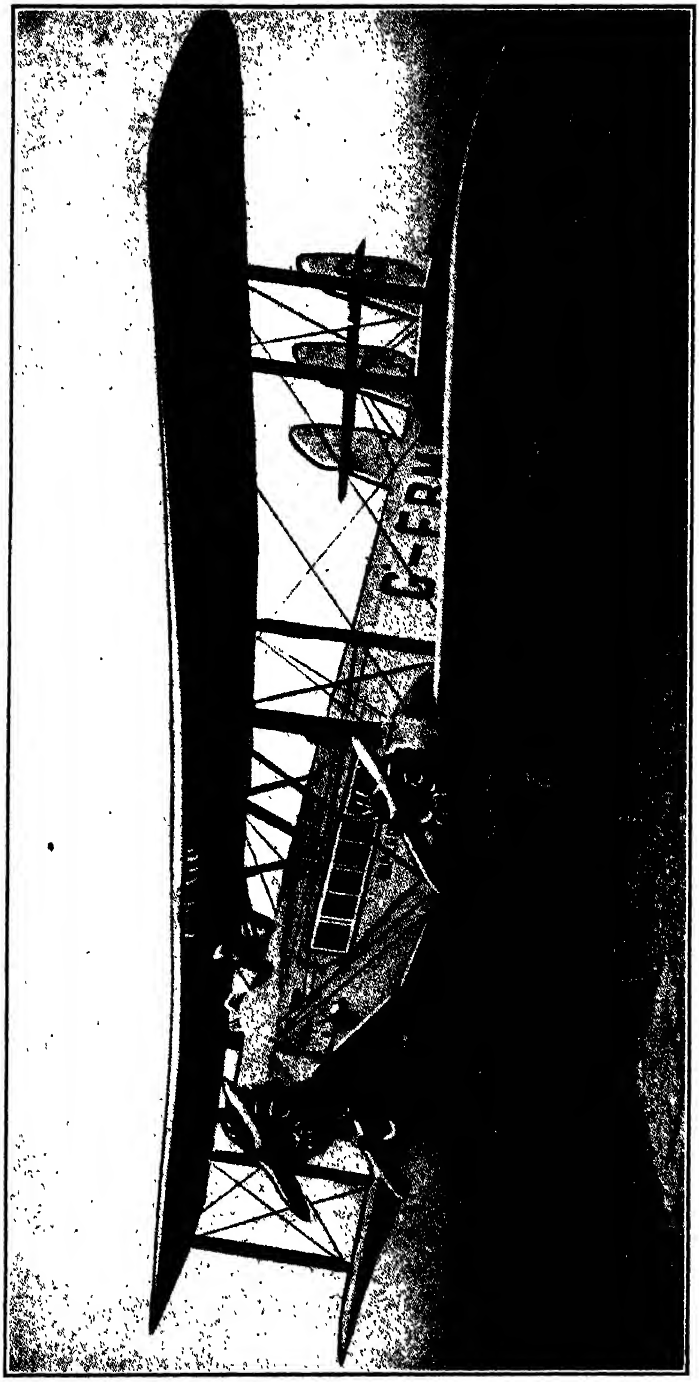


Fig. 360.—De Haviland "Hercules" Cabin Biplane Used by Imperial Airways on New Air Route between Cairo and Karachi. Three Air-Cooled Engines Used for Power.

ence in treating rice fields, this type of breeding place appears to be particularly well adapted to control by airplane dusting, because of the absence of trees and other obstructions which interfere with close flying. Even in such places as the heavily wooded areas where the water was protected by dense overhead foliage and where the planes had to be flown high enough from the ground to clear the tallest trees, the dust was found to have penetrated the thick growth and to have reached the water in sufficient quantities to destroy the larvae. The quantity of Paris Green used in the experiments varied from about one twentieth of a pound to several pounds per acre. Because of the small amount of poison required to kill the larvae, the Paris Green was mixed with an inert dust of some sort, finely ground silica earth being the carrier used in most cases.

Successful results have been obtained in dusting poison on the cotton crop in the South to control the boll weevil, as well as in dusting poison on swamps to control mosquitoes. Control of these two insects by airplane dusting may be said to have passed the experimental stage. Meanwhile many experiments have been carried out to determine the efficacy of airplane dusting in controlling a great many other insect pests, and very interesting results have been obtained.

One experiment consisted in dusting a small plot of catalpa trees badly infested by the catalpa sphynx. A small plane was used, carrying about one hundred pounds of lead arsenate and flying from twenty to thirty-five feet above the trees. Forty-six hours after the application the ground was literally covered with dead and dying caterpillars, and the effectiveness of the dusting was estimated at 99 per cent. It would have been almost impossible to poison the caterpillars by dragging a high-pressure land machine through the grove.

Successful experiments have also been made in dusting the gypsy moth in New England, and in dusting peaches in Georgia, against the curculio and the peach leaf curl. Leaf hoppers have been controlled in Mexico by airplane dusting.

One experiment which deserves particular attention consisted in dusting some apple orchards at Monroe, Oregon, against the coding moth. Both the airplane and the dusting equipment were makeshift, but the results showed that thirty-one pounds of dust per acre applied by the airplane were just as effective as forty-eight pounds per acre applied by a land machine.

Another very significant experiment was carried out on alfalfa near Ontario, Oregon, against the alfalfa weevil. In this case the dusting apparatus was improved, but the airplane was far from being suited for this kind of work. Calcium arsenate was used, and exactly two hundred acres were dusted in one hour, including two landings for materials. The average progress of a horse or motor drawn land machine doing the same work is about six to eight acres per hour. The worms began to show considerable mortality in the second day after dusting, although when dusted with land machines little or no mortality occurs until the third or fourth day. Later examination showed that the fields dusted by airplanes were almost entirely free of weevils. The cost of application was approximately one-third the cost of using a land machine, and there was no damage to the standing hay, as is unavoidable when land machines are used.

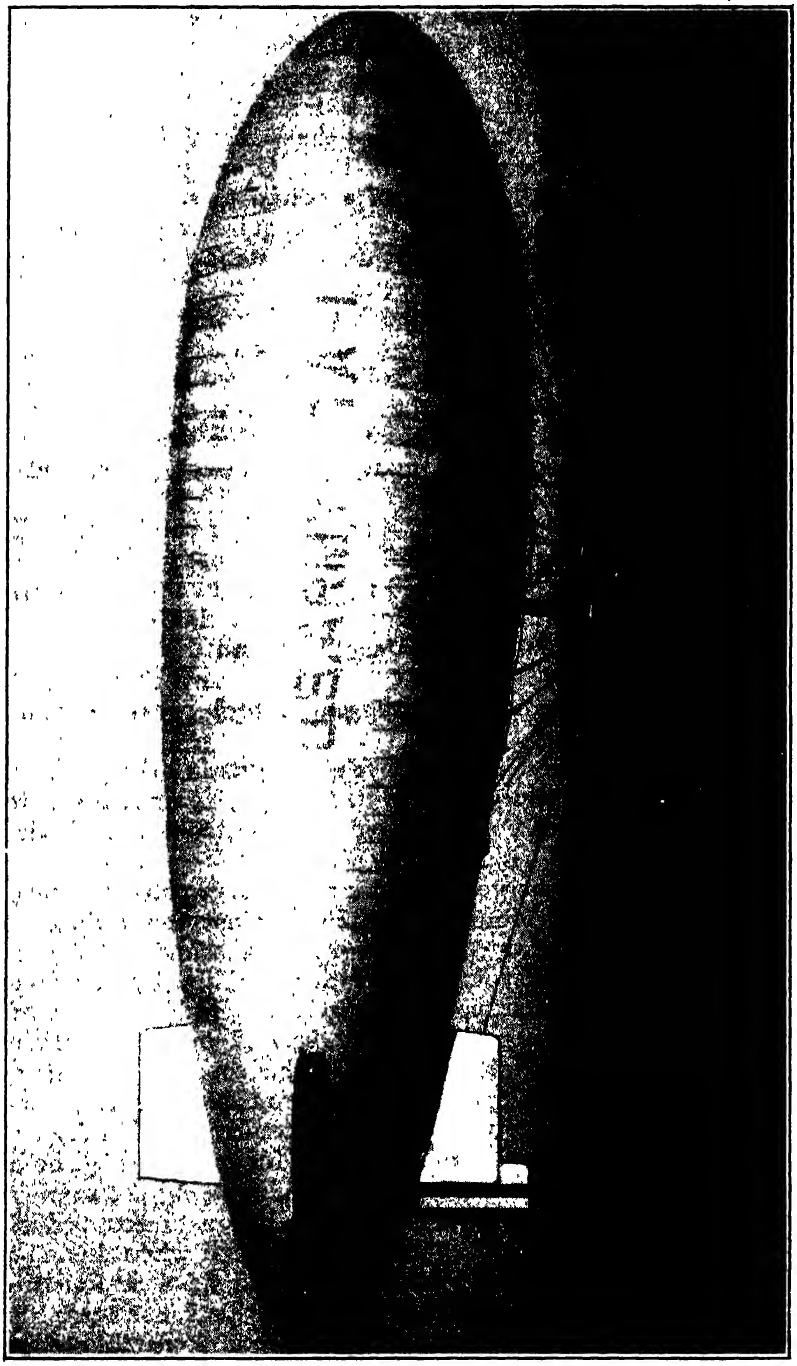


Fig. 361.—Official U. S. Army Air Service Photograph Showing Non-Rigid Airship at Scott Field, Belleville, Ill. This Type is Adapted for Military Rather than Commercial Use.

Airport and Landing Field Terms

airport—A locality, either of water or land, which is adapted for the landing and taking off of aircraft and which provides facilities for shelter, supply, and repair of aircraft; or a place used regularly for receiving or discharging passengers or cargo by air.

airship station—The complete assembly of sheds, masts, gas plants, shops, landing fields and related equipment required to operate airships and supply their needs. A station may include all or a part of the items enumerated. The base from which airships are operated.

apron—A hard surface area of considerable extent immediately in front of the entrance of a hangar or aircraft shelter which is used for the handling of aircraft or for repair in clear weather.

balloon bed—A mooring place on the ground for a captive balloon.

dock—A term sometimes applied to an airship shed.

docking rail—A rail or a guide, constructed on the landing field and extending into the shed which supplies a means for holding the lateral pull of an airship's docking or handling lines. The pull is transmitted to the rails from wheeled cars or trolleys which are fitted on or in the rails. Usually two rails are fitted at the greatest distance apart which will permit them to be run into the shed.

docking trolley—A car or trolley fitted on (or in) docking rails to transmit the pull of an airship docking line. It is fitted with wheels having antifriction bearings so it can move freely in the rail. Usually some sort of quick-release device for letting go the line is also fitted.

emergency landing field—A locality, either of water or land, which is adapted for the landing and taking off of aircraft, but which is not equipped with facilities for shelter, supply, and repair of aircraft and is not used regularly for the receipt or discharge of passengers or cargo by air.

ground cloth—Canvas placed beneath an aerostat for its protection during inflation and deflation.

ground gear—The gear, or equipment, necessary for the landing and handling of an airship on the ground.

hangar—A shelter for housing aircraft. More properly applied to heavier-than-air craft.

landing crew—A detail of men necessary for the landing and handling of an airship on the ground. A "ground crew."

landing field—A field of such a size and nature as to permit of aircraft landing and taking off in safety. It may or may not be part of an airport or air station.

landing T—A large symbol shaped like a capital T which is laid out on a landing field or on the top of a building to guide operators of aircraft in landing and taking off.

mast main mooring line—A line led from the main winch of a mooring mast through the mooring attachment at the top of the mast and carried out to a point on the ground well to leeward of the mast. The airship's main mooring line is attached to this line and the airship is hauled to

the mast by means of the joined lines. Sometimes called "ground wire" (British).

mast yaw line—One of the lines led from a winch at the base of the mooring mast through snatch blocks and carried out to leeward of the mast. The airship's yaw lines are attached to these lines. The snatch blocks are fixed to anchorages selected so that the joined lines tend to keep the airship into the wind and prevent her overriding the mast. These lines are also sometimes called "mast yaw guys" or "mast bow-steadying lines."

mooring drag—A movable and/or variable weight suspended from the after part of an airship's structure while moored at a mast to aid in restraining the vertical and lateral motions of the stern of the airship.

mooring mast—A mast or tower at the top of which there is mounted a fitting, so that the bow of an airship may be secured. It is usually provided with a ladder or staircase and a platform at the top, so that crew and passengers may enter or leave the airship, and also with piping for the supply of fuel, gas, and water. Sometimes called "mooring tower."

overhead suspension—A line leading from the roof of an airship shed and arranged to sustain the whole or a part of the weight of the structure of an airship when it is docked.

ram—The combination of tubes and springs which is mounted in gimbals at the top of a mooring mast. It consists of an outer tube which carries the gimbal mounting and within which slides an inner tube. The upper end of the inner tube carries the hollow cone which receives the airship's mooring cone and which is fitted to revolve freely. The inner tube can slide down into the outer tube and compress heavy springs, thus easing the shock when the mooring is made.

shed—A shelter for housing airships.

shore—A structural member for supporting the structure of a rigid or semi-rigid airship during building or docking, used in conjunction with (or without) a cradle.

snatch-block anchorage.—An anchorage set in the ground for a snatch block used with a yaw line from a mooring mast. The anchorages may be of concrete or timber and are usually arranged at equal intervals around the circumference of a circle whose center is the mast; may also be applied to any anchorage for a snatch block used in hauling down an airship or kite balloon.

three-point mooring—A system of mooring an airship. It consists primarily of three lines running from a mooring ring (or point) on the airship to three points on the ground. These points are usually at the vertices of an equilateral triangle. The lines may be secured to anchorages at the points or run over snatch blocks and to equalizing gear. The endeavor is to moor the airship in such a manner that the dynamic lift due to the relative wind shall keep the airship at a constant height from the ground. It may be considered as a substitute for a mooring mast, usually an emergency substitute.

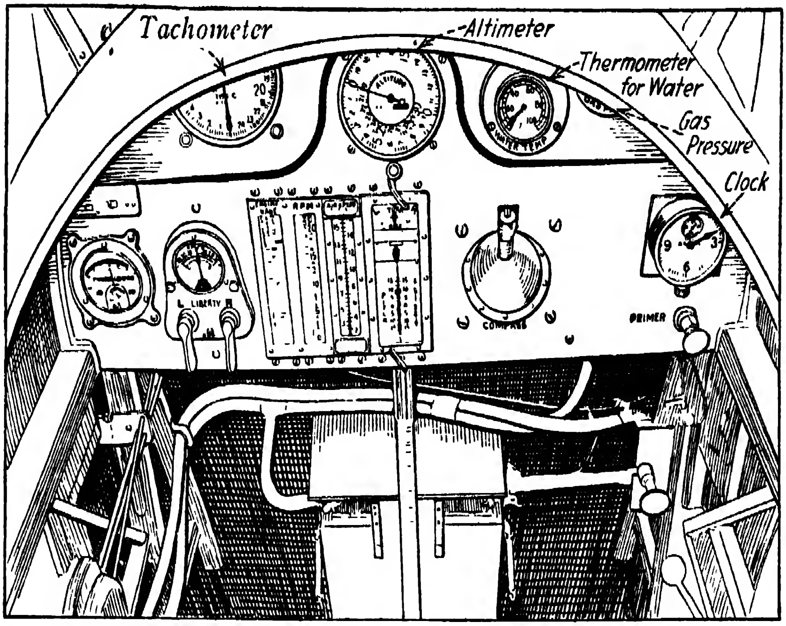


Fig. 362.—Instrument Board Showing Engine and Plane Performance Indicators and Airplane Navigation Instruments.

QUESTIONS FOR REVIEW

1. What factors made airlines established immediately after the World War unprofitable?
2. Outline some of the uses to which airplanes may be profitably applied.
3. What are the fundamental requirements of commercial airplanes?
4. Describe advantages of all-metal construction for commercial airplanes.
5. Name main items entering into a consideration of airplane operating costs.
6. How big should a landing field be for an airport?
7. What is the main consideration in making an airline profitable?
8. How much per mile does it cost to operate airplanes of various types?
9. Discuss airplane launching catapults and landing arresters.
10. What important aid to agriculture can the airplane render?

CHAPTER XVIII

AIRCRAFT INSTRUMENTS AND AERIAL NAVIGATION

Classes of Aircraft Instruments—Definitions of Instruments and Auxiliary Apparatus —Typical Instrument Boards—Instruments for Showing Air and Oil Pressure— Pioneer Engine Gauge—Fuel Level Gauge—Fuel Flowmeters—Distance Type Thermometers—Instruments for Supercharged Engines—Tachometers—Centrifugal Tachometer—Chronometric Tachometer—Tachometer Drives—Air Speed Indicators—Recording Air Speed Meter—Table XXIII, Air Speed Corrections—Air Speed Indicator Troubles—Air Distance Recorder and Speedometer—Aneroid Altimeters—Calibration of Aneroid Altimeter—Barographs—Rate of Climb Indicator—Turn and Bank Indicator—Flight Indicator—Anemometers—Magnetic Compass, Card Magnetic Type—Earth Induction Magnetic Compass—Installation and Compensation of Magnetic Compass—A Sun Compass—Radio-Direction Compass —Measurement of Drift—Airship Instruments—Manometers—Gas Pressure Alarms—Detectors for Gas Leakage—Measuring Gas Temperature—Resistance Thermometer—Thermo-couple Indicators—Statoscopes—Fire Extinguisher—Some Notes on Aerial Navigation—Night Flying—Plane Equipment for Night Flying— Influence of Weather.

The airplane is different from the motor car in that it is operated for the most part at the present time on uncharted airways whenever it departs from the few established airways that have been lighted and charted by the United States Air Mail or Army Air Service or that have been established by the Department of Commerce. For this reason aircraft making long trips must have all of the instruments that are needed in Marine Navigation. As so much depends on the engine, or engines, as the case may be, the airplane pilot must have a series of indicating instruments that will show how the power plant and its auxiliaries are functioning. A ship is navigated, when out of sight of landmarks by compass and sextant observations, but in addition to these, the navigator of an aircraft must also have instruments showing his direction and speed of travel vertically as well as horizontally. The pilot may be operating his airplane in a heavy fog, or in the clouds where he can not always place reliance upon his senses so various instruments must be provided by which he can be aided in controlling his airplane.

An airplane or airship, has a wide variety of instruments, some of which are merely modifications of devices previously used on automobiles and ships and a number that have been devised especially to meet the peculiar operating conditions found only in aircraft. For example, the tachometer that records the engine speed is a modification of the automobile speedometer, oil and pressure gauges are similar to like instruments in automobiles. The magnetic compass is a modified form of ship's compass. Then we have that class of special instruments such as Bank and Turn indicators, earth induction compass, rate of climb indicator and air speed indicator that have been developed mainly for aircraft use.

Classes of Aircraft Instruments.—It is not possible, in a book of this general character to devote the space that would be necessary to describe

completely the instruments, recorders and other devices that have been developed and found necessary in the operation and maintenance of military and commercial aircraft as a proper and adequate consideration of this subject demands a volume of its own. It is necessary, however, to briefly classify and describe the most important of such instruments for the benefit of those readers who seek general rather than specialized knowledge of any one branch of aeronautical science. The design and correct application of instruments is work on which a person might specialize for a lifetime without exhausting its possibilities. Instruments, in the opinion of the writer may be classified as follows:

(a) Engine Instruments: Switch, Ammeter (Battery System), Tachometer, Thermometers, Fuel and Oil Level Gauges, Fuel and Oil Consump-

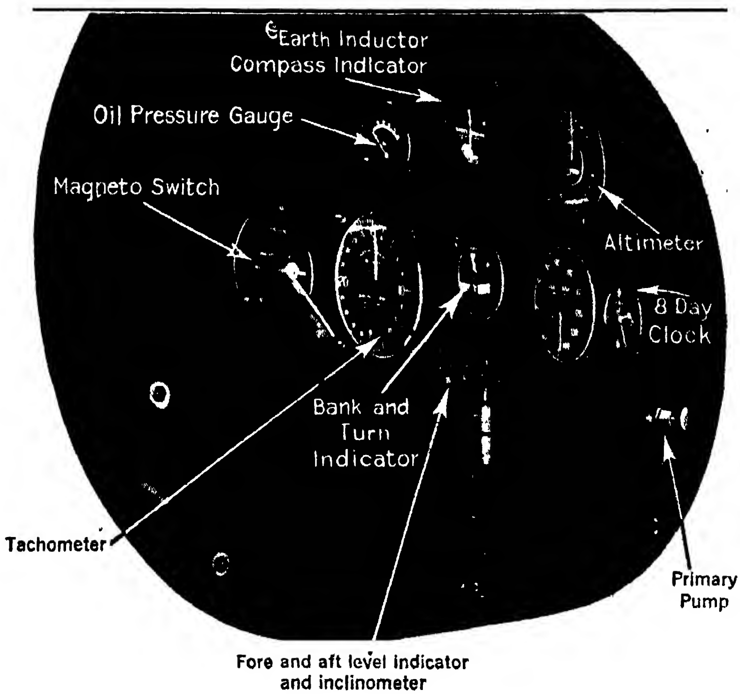


Fig. 363.—The Instruments Used on Lindbergh's Ryan Plane on his New York to Paris Flight.

tion Gauges, Engine Gauges, Air Pressure and Oil Pressure Gauges, Supercharger Indicators.

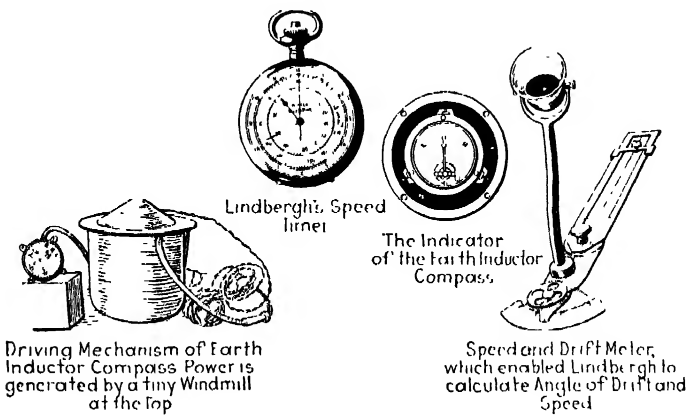
(b) Airplane Control Aids: Bank and Turn Indicator, Rate of Climb Indicator, Pitching Indicator, Air Speed Indicators, Altimeters, Anti-Stall Devices, Gyroscopic Control.

(c) Airplane Navigation Aids: Altimeter, Magnetic Compass, Earth Induction Compass, Goerz Sun Compass, Sextants, Clock, Air Distance Recorder, Drift Indicator, Radio Directional Compass.

(d) Special Airship Instruments: Manometers, Gas Pressure Alarm, Gas Leak Indicators, Gas Temperature Indicators, Statoscopes.

From the foregoing it will be evident that no attempt has been made to classify instruments having to do with military activities or radio communications. A fully equipped military airplane for reconnaissance or bombing is really a flying laboratory and arsenal because in addition to the instruments enumerated it carries armament, radio, camera, bomb dropping and sighting apparatus and other items not used in commercial aircraft for general applications. If operated at high altitudes, oxygen regulating and supply devices are necessary.

The following alphabetical list, with definitions given by the National Advisory Committee for Aeronautics in their Report No. 240, Nomenclature For Aeronautics, will serve to show the large variety of instruments and auxiliary apparatus developed for use with aircraft, and this by no means includes all of them.



Instruments Used by Charles Lindbergh on his Trans-Atlantic Flight, also by Other Pilots Who Followed his Example.

INSTRUMENTS AND AUXILIARY APPARATUS

accelerometer—An instrument for indicating, measuring, or recording accelerations.

air log—An instrument for measuring the linear travel of an aircraft relative to the air. One form consists of a windmill with a revolution counter.

air-speed meter:

air-speed indicator—An instrument for indicating the speed of an aircraft relative to the air. It is actuated by the pressure developed in a suitable pressure nozzle or against a suitable obstruction and is graduated to give true air speed at a standard air density. The speed indicated by the instrument is termed the "indicated air speed." (The indicated speed is a direct measure of the lift or drag exerted on the airplane at any altitude. Stalling at all altitudes occurs for the same value of the indicated speed.) (Fig. 363.)

true air-speed meter—An instrument for measuring the true speed of an aircraft relative to the air. The Biram and Robinson anemometers are of this type.

altigraph—An altimeter equipped with recording mechanism. Present instruments are of the aneroid type. The chart, driven by clockwork, is usually graduated in feet or meters in accordance with some empirical or arbitrary pressure-temperature-altitude formula. In other words, it is a barograph whose scale is designed to read heights. (Fig. 384.)

altimeter—An instrument for measuring or indicating the elevation of an aircraft above a given datum plane. (Fig. 363.)

anemometer—An instrument for indicating or measuring the speed of an air stream. (Fig. 390 C.)

aneroid altimeter—An altimeter, the indications of which depend on the deflection of a pressure-sensitive element. The graduations of the dial correspond to an empirical or arbitrary pressure-temperature-altitude formula. (Figs. 382, 383.)

ballonet-fullness indicator—An instrument for indicating the volume of air in a ballonet.

barograph—An instrument for recording the barometric or static pressure of the atmosphere. (Fig. 384.)

drift bar—A part of a drift meter or other instrument for indicating the apparent direction of motion of the ground relative to the fore-and-aft axis of the aircraft. It usually consists of a wire or arm which can be set along this direction of motion. Cf. drift.

drift meter—An instrument for measuring the angle between the fore-and-aft axis of an aircraft and its path over the ground. One form consists of a drift bar provided with a suitable angular scale. Cf. drift. The instrument is graduated to read correctly when it is level.

electrical-capacity altimeter—An altimeter, the indications of which depend on the variation of an electrical capacity with distance from the earth's surface.

engine altimeter—An altimeter for indicating the altitude corresponding to the pressure produced in the intake manifold of a supercharged engine.

flight indicator—An instrument in which a lateral inclinometer or a pitch indicator, a fore-and-aft inclinometer, and a turn indicator are combined to form a compact unit. (Fig. 390 A.)

flight recorder—An instrument for recording certain elements of the performance of an aircraft.

gas-cell alarm—A device, fitted adjacent to a gas cell, which indicates or warns when a predetermined limiting pressure has been reached in the gas cell. Also called "pressure alarm."

ground-speed meter—An instrument for measuring the speed of an aircraft relative to the ground. In present types of instruments some reference line in the instrument must first be set parallel to the apparent direction of motion of the aircraft with reference to the ground before the speed measurement is made. This is usually accomplished by the use of a drift meter, the adjustment of which automatically orients the ground-speed meter properly. Thus both the magnitude and direction of the motion of the aircraft with reference to the ground are obtained.

gyroscopic turn indicator—A turn indicator dependent on gyroscopic action.

inclinometer—An instrument for indicating the attitude of an aircraft. Inclinometers are termed fore-and-aft, lateral, or universal, according as

they indicate inclination on the vertical plane through the fore-and-aft axis, or in the vertical plane through the lateral axis, or in both planes, respectively.

induction compass—A compass, the indications of which depend on the current generated in a coil revolving in the earth's magnetic field. (Fig. 363.)

absolute—An instrument which indicates the attitude of an aircraft with reference to the vertical. The indications of instruments of this type usually depend on gyroscopic action.

relative—An instrument which indicates the attitude of an aircraft with reference to apparent gravity; i.e., to the resultant of the acceleration of the aircraft and that due to gravity.

kymograph—An instrument for recording the angular oscillations of an aircraft in flight with respect to axes fixed in space. The reference direction is usually given by a gyroscope or beam of sunlight.

leak detector—An instrument which detects the presence of hydrogen and other light gases in the air and which can be adapted to find leaks in a container inflated with such a gas.

mechanical stabilizer—A mechanical device to prevent an aircraft from departing from a condition of steady motion, or, in case such a motion is disturbed, to restore it to its steady state. Includes gyroscopic stabilizers, pendulum stabilizers, inertia stabilizers, etc.

optical altimeter—An altimeter, the indications of which depend on the manipulation of a suitable optical system.

pitch indicator—An instrument for indicating the existence of a pitching velocity of an aircraft. Cf. turn indicator.

Pitot tube—A cylindrical tube with an open end which is pointed upstream (i.e., so that the air meets the instrument head-on or is met head-on by the instrument). When the aircraft is flying less than about 200 miles per hour, the instrument measures the impact pressure. When used on aircraft, it is usually associated either with a closed coaxial tube surrounding it or with a closed tube placed near it and parallel to it, the combination being termed a Pitot-static tube. The associated tube has perforations in its side so that it is subjected to static pressure, as distinct from impact pressure. The speed of the fluid can be determined from the difference between the impact pressure and the static pressure, as read by a suitable gauge. In common terminology, the Pitot-static combination, as above, is often termed simply a Pitot tube or Pitot. (Fig. 375 C.)

power Venturi—A Venturi tube used to operate gyroscopic turn indicators and other instruments. (Fig. 390 B.)

pressure nozzle—An instrument which, in combination with a gauge, is used to measure the indicated speed of an aircraft relative to the air. It may be a Pitot-static or a Venturi tube, or a combination of a Pitot tube and a Venturi tube.

sound-ranging altimeter—An altimeter, the indications of which depend on the measurement of the time required for a sound wave to travel from the aircraft to the earth and back.

speed-indicating Venturi—A Venturi tube may be combined with a Pitot tube or with a tube giving static pressure to form a pressure nozzle which may be used to determine the indicated speed of an aircraft through the air. The pressure difference is measured by a suitable gauge.

static turn indicator—A turn indicator actuated by the difference in pressure between static tubes mounted near the wing tips equidistant from the plane of symmetry and in a plane parallel to the lateral axis.

statoscope—An instrument for detecting minute changes of altitude of an aircraft. The indications of the instrument usually depend on small changes of the static pressure of the air.

superheat meter—An instrument for measuring the difference in temperature between the gas in a gas container of a lighter-than-air craft and the surrounding air.

thermograph—An instrument for recording the temperature.

turn indicator—An instrument for indicating the existence of an angular velocity of turn of an aircraft about the normal axis. In horizontal flight it indicates the presence of a yawing velocity. "Turn meter" is the term applied to certain types. (Fig. 363.)

Venturi tube—A short tube with flaring ends and a narrow or constricted section between them, into which a side tube opens. When fluid flows through the Venturi, there is a reduction of pressure in the constricted section, the amount of the reduction being a function of the velocity of flow. (Fig. 390 B.)

vertimeter—A device for indicating the rate of rise and fall of an aerostat, usually a special form of statoscope. A rate-of-climb meter serves the same purpose, although of a different form.

windmill—An air-driven screw used to drive auxiliary apparatus on an aircraft.

yawmeter—An instrument for measuring the angle of yaw.

Typical Instrument Boards.—The instrument board of a United States Army airplane equipped with Liberty motor is shown at Fig. 362. Some of the instruments are of the round dial type, others have vertical scales. At the top of the cockpit are placed the rate of climb indicator, an altimeter, a thermometer for indicating water temperature and a gas pressure gauge. At the extreme right a clock and engine primer pump are mounted. At the extreme left the reader can discern the ammeter of the Pioneer induction type compass. Next to that is the switch controlling ignition of left and right banks of motor cylinders, also ammeter showing current flow to and from storage battery. In the center of the panel are grouped an engine gauge, a vertical scale tachometer, a vertical scale air speed indicator and a turn, bank and pitch indicator. The earth inductor compass is shown at right center. The storage battery used for ignition of the Liberty motor is shown just below the instrument board and forward of the control stick.

The instruments shown at Fig. 363 show the essential plane navigating instruments that are needed on all airplanes. No engine or power plant instruments are shown in this group, which has been manufactured by the Pioneer Instrument Company of Brooklyn, New York. This assembly comprises an altimeter, clock, turn and bank indicator, air speed indicator

and earth induction compass. All scales are of the round dial type and radiolite dials, which can be read in the dark are provided on all instruments.

To demonstrate and test out their instruments in actual flight, the Pioneer Instrument Company have equipped a standard airplane with two sets of instruments, one acting as a check on the other, shown at Fig. 364. This is known at the "flying show case." The instruments in the front cockpit which are shown in an enlarged view at Fig. 365 include the round type dial instruments as follows: Oil pressure gauge, thermometer, air

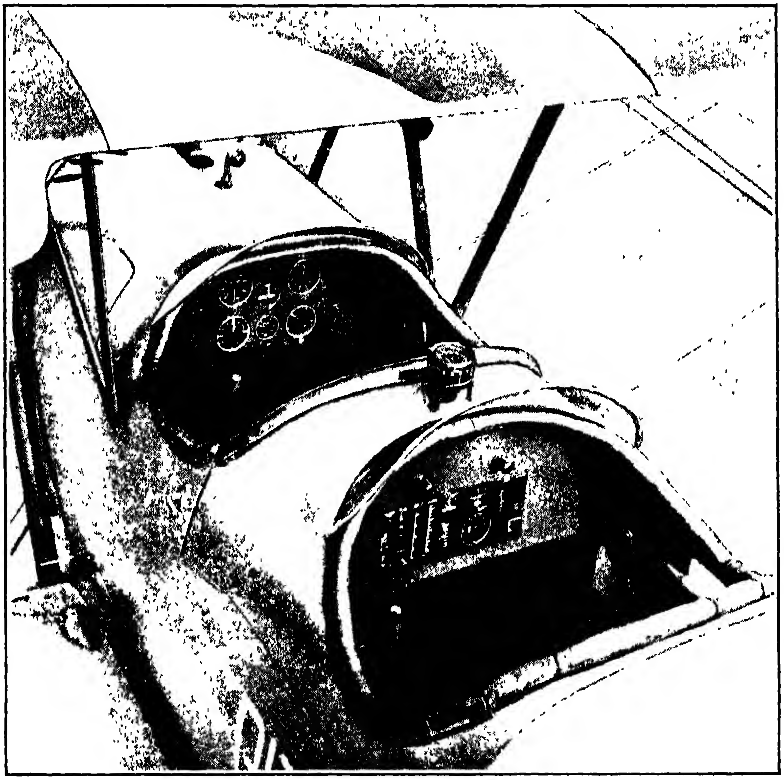


Fig. 364.—View Showing Cockpits of Specially Equipped Airplane Used by Pioneer Instrument Company to Demonstrate its Product and Test it in Actual Flight.

speed indicator, tachometer, earth inductor compass and indicator, turn and bank indicator, fuel level gauge, rate-of-climb indicator, altimeter and clock. The instruments in the rear cockpit are of the vertical type. The assembly includes an engine gauge unit which has thermometer and oil pressure gauges, a fuel level gauge, tachometer, air speed indicator, a flight indicator comprising turn, bank and pitch indicators, earth inductor compass comprising indicator and controller, a rate of climb indicator, altimeter, air distance recorder and watch. The center section carries a wing type compass. The fuselage at the front of rear windshield supports a small type compass of the magnetic type. In front of the front windshield

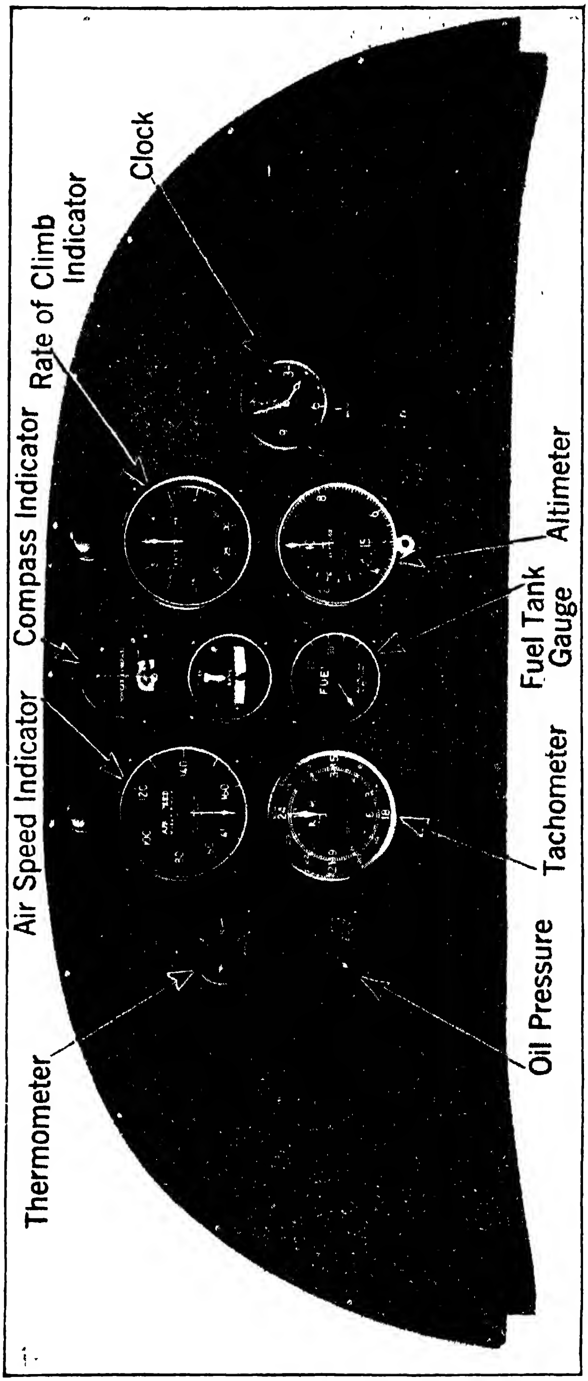


Fig. 365.—Instrument Board Removed from Front Cockpit of Special Travel Air Biplane Used to Demonstrate Pioneer Instruments.

the static ball for equalizing pressure in fuel tank and in fuel gauges is mounted. A drift and speed indicator is secured to the right of rear cockpit. The generator for the earth induction compass is mounted at the rear of the rear cockpit, (not shown in photograph). A venturi tube is mounted on the right center section strut to operate turn and flight indicators and the pitot-static tube to operate the air speed indicator and the air distance transmitter is attached to the front of the left wing struts.

The instrument boards shown at Fig. 366 are those of Fokker Universal monoplanes used by the Colonial Airways, Inc. these having practically the same instruments. The upper panel has magneto switch, tachometer,

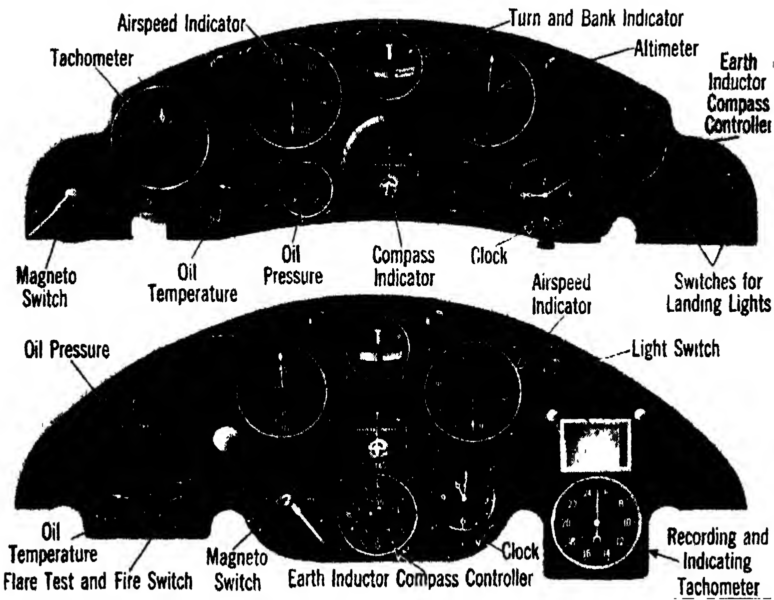


Fig. 366.—Instrument Boards Used on the Fokker Universal Monoplanes Flown by Colonial Airways, Inc.

thermometer, oil pressure gauge, air speed indicator, turn and bank indicator, earth inductor compass indicator, altimeter, clock, compass controller, landing light switches, navigation light switch and lights and rheostat for same. The panel shown below it has a different type of tachometer incorporating recording and indicating mechanism. In addition to the instruments shown on the upper panel, the lower one carries a flare testing and firing unit and a primer to facilitate engine starting.

Instruments for Showing Air and Oil Pressure.—Practically all gauges used to indicate pressure variations in flow of fluids, whether gaseous or liquid operate on the principle of the Bourdon tube, which has been used for many years for indicating steam and air pressure. The general internal arrangement is clearly shown at Fig. 367 which is a simple diagram outlining the principle of action. The tube is bent in the form of a question mark or hook and is of flattened section and made of springy material such

as brass, bronze or steel, depending upon the amount of pressure it is expected to withstand. The tendency of the pressure inside the tube is to straighten it out, the amount of movement depending on the internal pressure. The tube has spring enough to return to its normal position when the pressure is released. The free end of the bent tube is connected to a gear sector in such a way that as the tube tends to straighten, the connecting link between the end of the tube and the sector or actuator transmits the motion of the end of the tube, rocks the sector which in turn moves the pointer by turning the pinion meshing with the sector and attached to the pointer

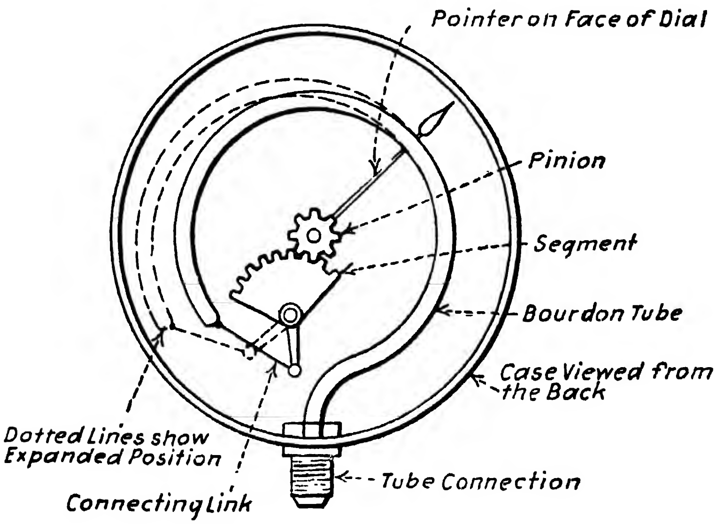


Fig. 367.—Simplified Diagram Showing Internal Construction and Principles of Action of all Pressure Indicating Instruments Using the Bourdon Tube.

shaft. In other forms of instruments the Bourdon tube may be replaced by a flexible diaphragm attached to multiplying gearing to amplify the relatively small movement of the diaphragm under pressure variations to a motion of the indicating needle of sufficient amplitude so it may be read easily. A movement of only a few one-thousandths of an inch of tube or diaphragm may produce a linear movement of the pointer relative to the scale that will cover the space of several graduations.

Pioneer Engine Gauge.—This unit combines within a single instrument indicators of Fuel Pressure, Water or Oil Temperature and Oil Pressure. It replaces three separate round-dial instruments and actually occupies less instrument board area than any one of the three alone. With a vertical tachometer this instrument forms a complete power plant unit. The temperature element used in the Pioneer Engine Gauge Unit is a specially designed Boyce Motometer. This element was adopted after an exhaustive series of tests. Both pressure elements are of Pioneer design and manufacture. The dial of the engine gauge is shown at Fig. 368 A. While a

side view of the triple compartment casing is shown at Fig. 369 so the general construction can be understood.

Engine Gauge Units are made in two models. In type 106, which is illustrated at the left, all three elements are contained in a single housing while in type 173B each element has its individual case which may be removed independently of the other two. Type 106 weighs 1.8 pounds and

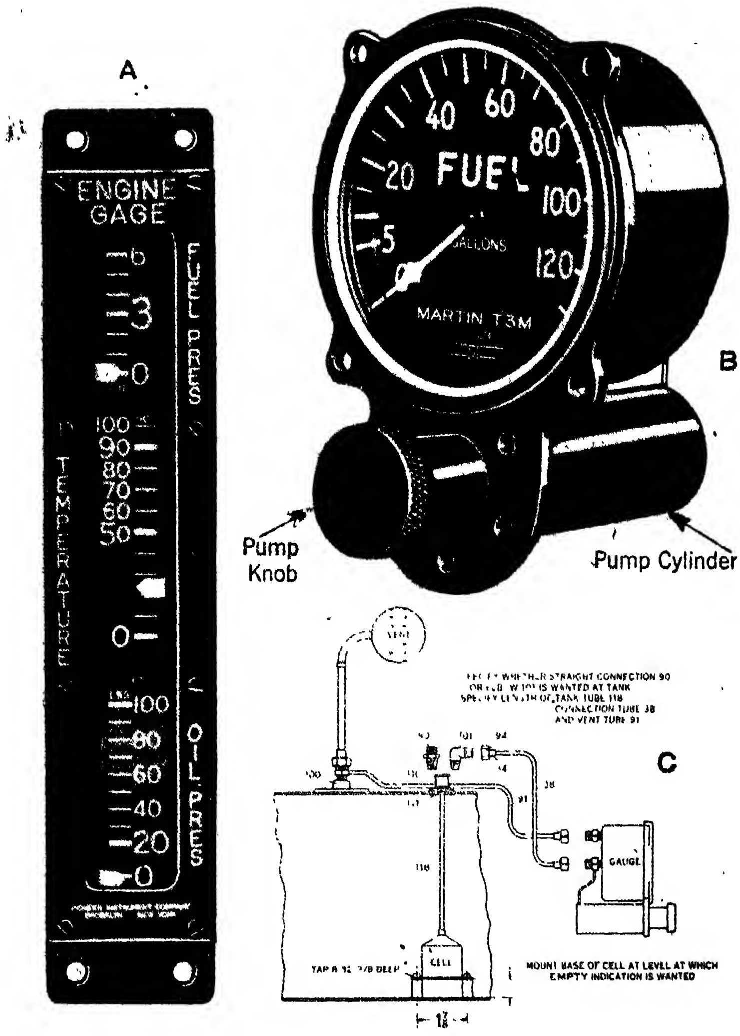


Fig. 368.—Pioneer Engine Gauge at A Combines Pressure and Temperature Indicators. B—Distance Type Fuel Level Indicator. C—How Fuel Indicator is Installed.

type 173 B 2.3 pounds. Standard ranges are 0-6 pounds per square inch for Fuel Pressure, 0-100 degrees C for temperature, and 0-100 pounds per square inch for oil pressure. Higher range oil pressure units can be supplied on special order. Temperature units are regularly furnished with

12½ feet capillary tubes. Longer or shorter tubes can be supplied, however.

Installation of Pioneer Engine Gauge.—The Engine Gauge Unit is mounted in the instrument board in the same way as any other vertical scale instrument. Pressure elements are fitted with 7/16 inch by 20 thread male connections. Run the fuel and oil pressure tubes from the proper places on the fuel line and engine to the back of the gauge, avoiding sharp bends and fastening securely at short intervals to prevent vibration. Slip a union nut over each tube and solder connection nipples to the tube ends. Nuts and nipples are standard tube fittings and are not furnished with the Unit unless specially ordered. Clean and oil threads on the gauge connections. Tighten union nut until nipple seats properly to make a tight joint. Avoid excessive strain on the instrument.

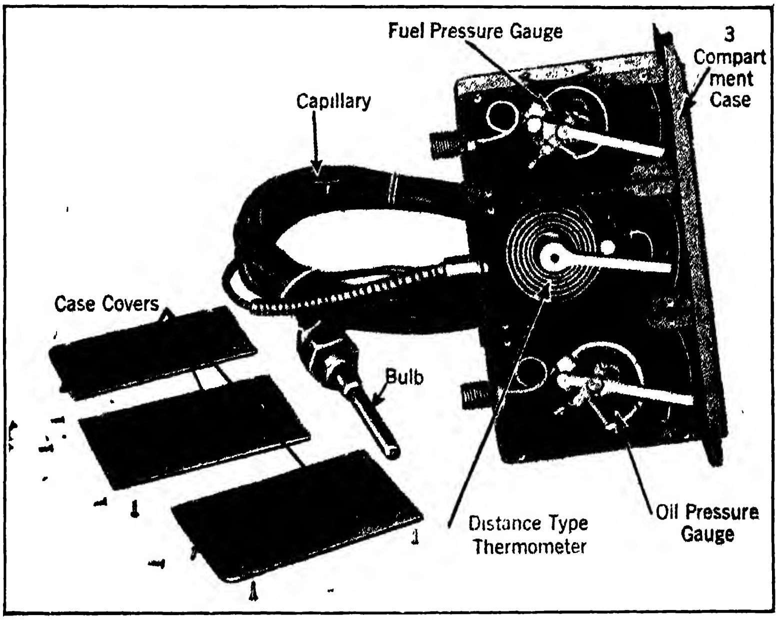


Fig. 369.—Side View of Pioneer Engine Gauge with Covers Removed to Show Method of Combining Pressure and Temperature Indicating Instruments.

The bulb on the end of the thermometer tubing is fastened in the radiator or at any other point in the water or oil system where it is desired to measure the temperature. The bulb is held in place by a clamp nut ⅝ inch diameter by 18 threads per inch which is screwed into a similarly tapped hole. Extreme care should be taken in handling the thermometer bulb and tubing. Be careful not to dent the thermometer bulb or bend the thermometer tubing too sharply. If the tube is too long, it may be coiled without affecting the accuracy of the instrument, but the coil must be carefully secured to prevent vibration from loosening the joints at the bulb or at the instrument.

WARNING. Do not under any consideration tamper with the Engine

Gauge Unit mechanisms. They are assembled at the factory by skilled instrument makers and if damaged should be returned to them for repair.

Fuel Level Gauge.—The Pioneer fuel level gauge shown at Fig. 368 B, continuously and accurately indicates the amount of fuel in the tank to which it is connected. The importance of such a gauge can hardly be overestimated. By knowing exactly how much fuel is available at all times it is unnecessary to carry a large excess "just to be on the safe side" and still there is no change cf unexpectedly "running out of gas" with the consequent forced landing and possible crash.

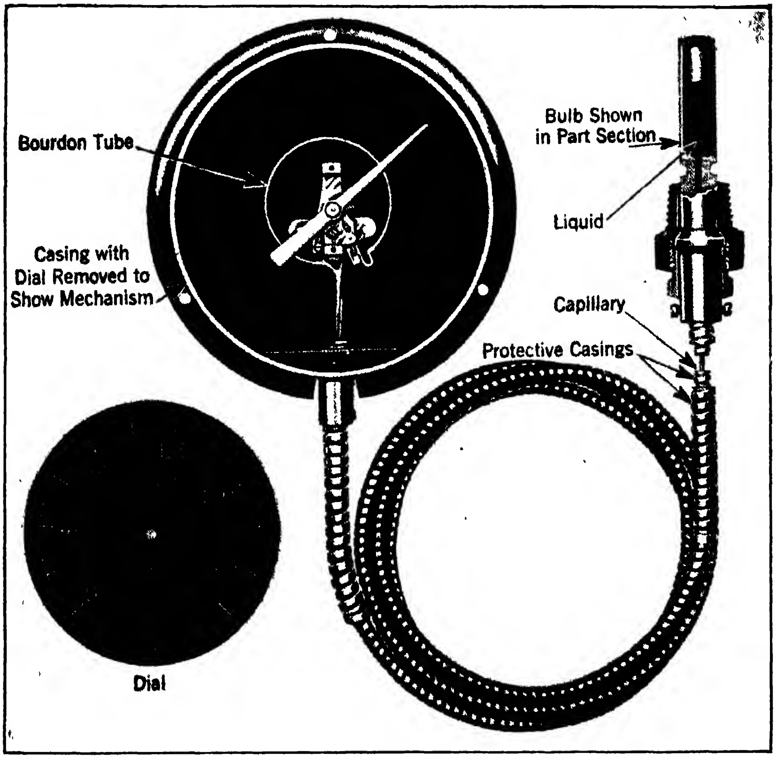


Fig. 370.—The Foxboro Distance Type Thermometer with Bulb Shown in Part Section and Dial Removed from Casing to Show Bourdon Tube.

The operation of this gauge depends upon the simple principle that the pressure exerted by a volume of liquid is proportional to its depth. A "hydrostatic cell," forming part of the guage system, is placed at the bottom of the tank as shown at Fig. 368 C. This cell is filled with air, and the weight of the liquid above it compresses this air. A small tube runs from the cell to a fitting on the outside of the tank, and from the fitting a connection tube goes to the gauge. These tubes transmit the air pressure to the gauge, which is a sensitive pressure indicator and is calibrated so that this air pressure is translated into gallons of fuel or other units of weight or volume.

This would complete the system were it not for the fact that because of the expansion of the air in the cell and tubing, due to changes in tempera-

ture and altitude, a certain small amount of air is occasionally lost. To assure the accuracy of the indication the balance of the system must be maintained by replacing the lost air. For this purpose a small pump is built into the gauge unit. Once a day, or whenever it is desired to know the fuel level with absolute accuracy, the knob of the pump is pulled out once and released. On the return stroke, the pump automatically introduces the correct amount of air to balance the system and restore accuracy of readings. It is not necessary to operate the pump each time the gauge is read, as the indication is continuously correct except for slight errors due to temperature and altitude. It will be evident that pressure on top of the fuel and within the gauge case must be identical if correct readings are to be obtained. Both the tank and gauge must be vented to assure

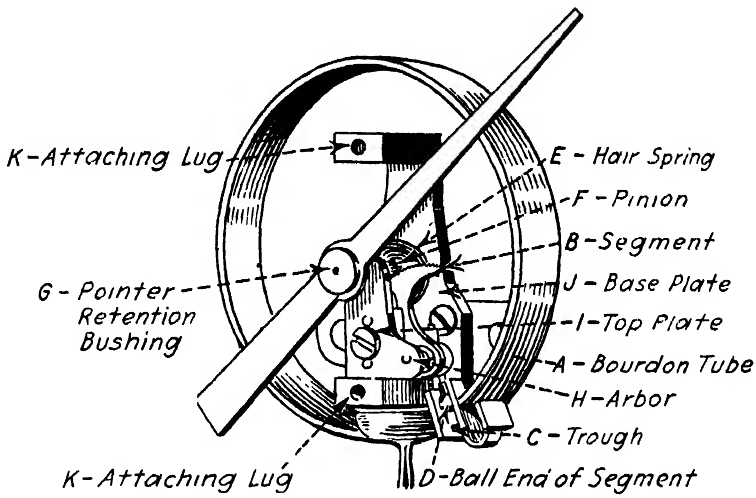


Fig. 371.—Mechanism of Foxboro Distance Type Thermometer Removed from Casing Showing Parts and Their Relation to Each Other.

equality of pressure. A special vent unit may be used, but in many cases it is equally satisfactory to terminate the vent pipe from the gauge and from the tank at approximately the same point. These gauges are made and calibrated to indicate the fuel level in tanks of any size or shape and a gauge for one size and shape of tank will not indicate correctly if installed with a different tank. Complete information must be given the makers showing size and shape of tank, material of which it is made, capacity of tank, method of venting, etc., in order to permit them to supply an instrument that will indicate correctly.

Fuel Flowmeters.—Various other forms of fuel level gauges have been devised, some operating by electrical means, others by simple float and leverage systems in which the indicators are mounted directly on the tank. There is still another form of fuel indicator, this being known as a flowmeter, this indicating the amount of liquid being consumed by the engine in terms of gallons per hour. In the R. A. F. flowmeter a vane is rotated

by the liquid against the retarding effect of a spring of the spiral or hair spring type. For every position of the vane there is a corresponding rate of flow for any liquid. The scale shows consumptions from 5 to 30 gallons per hour. The device is interposed between the fuel tank and the carburetor float bowl and all fuel going to the engine must pass through it.

Distance Type Thermometers.—Instruments used for indicating temperature of cooling water or engine lubricating oil consist of four parts if the reading is to be at a point remote from the source of heat. An ordinary form of thermometer is not suitable because the bulb and scale are integral. In the distance type, the bulb is placed in the water system or in the oil container while the indicator may be located on the instrument board. The parts are the bulb, coupling, capillary and indicator. The principle of operation is the same as that of a standard thermometer. A difference in temperature produces a change in volume and pressure of the liquid in the bulb. In a mercury thermometer, the mercury is increased in volume or expanded by rising temperature and decreased in volume or contracted by falling temperature. When the heat increases, there is no longer sufficient room in the bulb and the mercury must rise in the tube attached to the bulb because its expansion has required more space. The hotter the bulb gets, the greater the distance the mercury column raises in the tube. By suitably calibrating the tube, the temperature may be read from the point on the scale that corresponds to the top of the mercury column. In the distance type, the bulb is filled with a liquid of high vapor pressure such as sulphur dioxide or methyl chloride. Under varying temperature and the consequent variations in pressure the gauge is actuated because the bulb and capillary transmit the pressure to the helical tube located in the case, which is in effect a series of Bourdon tubes joined end to end. Owing to the great length of the tube, no multiplying devices are necessary in some of the gauges. The tube is firmly mounted in the case at one end and operates the indicating pointer shaft from the other. The gauge dials may be marked in Centigrade or Fahrenheit degrees. If Centigrade is used, the markings range from 0 to 100 degrees. Care must be taken not to cut or kink the capillary tube when installing these instruments, if the capillary is too long, it should be coiled to take up any excess in length.

The interior of the casing of the Foxboro distance type thermometer with dial removed to show arrangement of parts is depicted at Fig. 370. The dial is calibrated in Farenheit degrees though any thermometer scale can be obtained. The enlarged view of the mechanism at Fig. 371 will enable the reader to understand the method of operation.

Referring to Fig. 371—the Bourdon Tube "A" is made from special FOXBORO bronze by a new process which insures uniformity of contour, elasticity, and durability; it positively will not "set" or split; it is permanent in calibration. A Bourbon Tube of one convolution, as illustrated, or of several forming a helix, can be produced with greater accuracy and will have more resiliency than the spiral or any other form tube. To obtain the long deflection of the pointer, the motion of the free end of the tube, produced by the changes in temperature, is multiplied by a unique rack and pinion movement. Although similar to that used in Bourdon Tube pressure gauges, it is free from lost motion, and friction is negligible.

A special design of tip on the end of the Bourdon Tube forms a trough "C" in which the ball end "D" of the segment "B" is free to move. As the tube "A" expands it releases the ball end "D," which is forced to follow in contact with trough "C," due to the tension of the hair-spring "E" on the pinion "F" in mesh with the segment "B." The pointer is securely fastened to the tapered end of the pinion "F" by the drive-fit bushing "G," and is deflected a definite amount proportionate to the movement of the free end of the tube "A." By obtaining the moving power for the light aluminum pointer from the released hair-spring there is absolutely no lost motion either up or down the scale. This construction is patented, and has made possible the long open scale and accuracy found in FOXBORO Dial-Type Thermometers.

The base plate "J" is a hard alloy die-casting with bronze bushings for the pinion "F" and the arbor "H," which are made of nickel silver. The segment "B" and the top plate "I" are made of hard bronze. The top plate "I" is secured by a large fillister head screw and two dowel pins which positively insure alignment of the moving parts. The dial is fastened to the base plate "J" by screws in the tapped holes "K," making an integral actuating movement which eliminates every possibility of destroying the calibration.

The materials, dimensions, and methods used to produce these non-corrosive parts insure long life. The skill gained by long experience in instrument manufacture makes the production and use of this improved movement possible, and gives the user of these thermometers the advantage of a long, open, easily read scale with a guaranteed accuracy of within less than one per cent of total scale reading throughout the entire range. FOXBORO Thermometers can be used continuously at the top of the scale without injury.

Instruments for Supercharged Engines.—The various engine instruments described are used normally with engines without supercharges and while they are used with supercharged engines as well, several additional devices are required. The compressed air coming from the supercharger discharge port must be cooled before it goes to the carburetor and it is passed through a cooling apparatus known as an intercooler before going into the carburetor air intake. In order to have the engine work properly, the temperature of the compressed air should be measured when it leaves the compressor and after it leaves the intercooler. Another needed indication is the air pressure at the carburetor and the difference in pressure between the outlet of the gasoline pump and carburetor should be known.

The temperature of the air when it leaves a turbo-compressor type of supercharger is high and is best measured with an electric thermo-couple thermometer with a voltmeter indicator calibrated in degrees. Any type of thermometer can be used to measure the degree of heat of the air leaving the cooler. To measure the absolute pressure of the air at the carburetor, a standard aneroid barometer is enclosed in an airtight casing, joined to the carburetor air intake. To measure the differential pressure, a tube from the gasoline pump is joined to a pressure gauge working on the Bourdon tube principle, this also being enclosed in an airtight case, the pressure of the air surrounding this gauge being the same as that of the carburetor

entering air. These pressure gauges and thermometers are made up in pairs and in latest types of instruments, the cases are provided with vertical dials. This makes it easy for the pilot to make the necessary comparative readings. The instruments do not differ in principle from similar temperature and pressure indicators employed with normal engines.

Tachometers.—These instruments are very useful for the reason that they give a continuous index to the condition of the motor and the power produced by apprising the pilot of the number of engine revolutions. They also are useful in normal flying by showing climb or dive because the engine will tend to slow down on a climb and accelerate on a dive or glide with a fixed throttle setting because it is working against gravity when climbing and is helped by gravity when the plane is gliding or diving. Any derangement in the engine mechanism or in the carburetion and ignition systems will be shown by a reduction in engine speed. Tachometers are of use in performance tests, not only in assisting the pilot to maintain the same speed in level flight, and otherwise control the machine, but also in checking the airspeed calibration, in judging the performance of the engine and in judging propeller performances.

For use in an airplane the tachometer must be light, small, rugged and entirely self contained. It has most difficult conditions to meet, such as violent accelerations in various directions, shocks, high and very low temperatures, and changes in air-density. For this reason certain types of automobile speedometers are quite unsatisfactory for use in the air. In ordinary flying, consistency is more important than accuracy, since the tachometer is then used as a danger signal, but in performance tests, accuracy is absolutely essential to the determination of results which will make possible comparisons of value.

The following classification is due to Dr. Washburn of the Bureau of Standards.

(1) *Chronometric tachometers.*—In this type, the distance through which a toothed rack moves, or the angle through which a gear rotates while held in mesh with a rotary pinion for a fixed interval of time, is proportional to the average speed of revolution of the pinion during the interval.

(2) *Centrifugal tachometers.*—These operate on the same general principle as the governors used on steam engines. Two weights mounted opposite one another or inclined at opposite angles on a vertical shaft, tend to fly apart or to revolve in line with one another as the shaft revolves. The position of the weights is roughly proportional to the speed of the shaft. A typical centrifugal instrument, Johns-Manville, is shown at Fig. 372.

(3) *Air drag or viscosity tachometers.*—Where two surfaces separated by a very narrow air space are in relative motion, they exert on each other in virtue of air friction or viscosity, a force which under certain conditions is proportional to the rate of motion. This type of tachometer is not used to any great extent in airplanes.

(4) *Air leak tachometers.*—The pressure generated by an air pump driving air through a leak orifice of properly regulated size is proportional to the speed of revolution of the pump.

(5) *Magnetic drag tachometers.*—When a permanent magnet is revolved near to a fixed electrically conducting drum or disc, the turning force

exerted on the drum, in virtue of the electric current induced in it is proportional, within certain limits, to the rate of revolution of the magnet.

(6) *Electric tachometers.*—These depend on the fact that the electromotive force or voltage of a well constructed magneto is nearly proportional to the speed of rotation of the armature. They consist of a magneto in electrical connection with a voltmeter calibrated in r.p.m. instead of units of electromotive force.

The forms in common use are of two types, chronometric or centrifugal and in testing work either type is used. The latter is so simple in operation that its principle of action can be understood by any one who has ever seen a steam engine governor in action. As the speed increases, the governor weights swing out, pulling up a flat collar on the shaft that in turn pushes up a shoe that actuates a pointer through rack and pinion. The weights work against the retarding effect of a spring and when the speed and the centrifugal forces diminishes, the weights tend to come together again. Such a device is not affected by magnetism or temperature to any appreci-

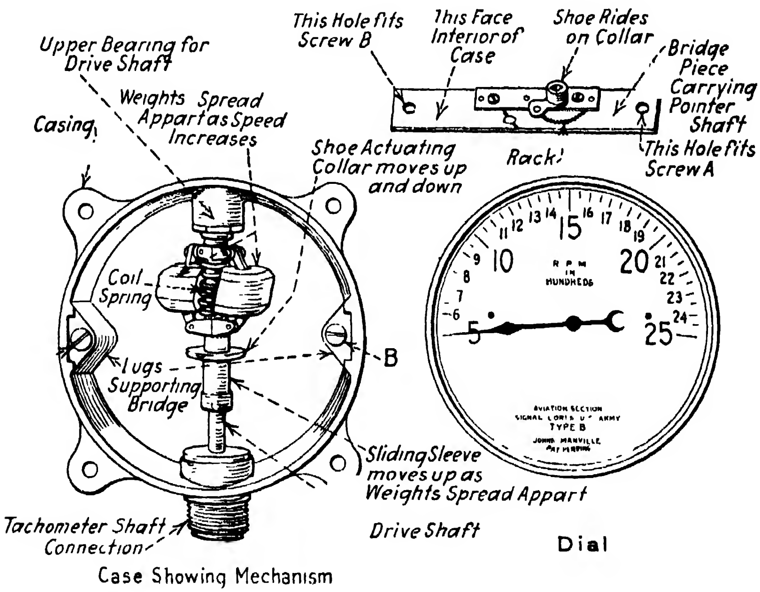


Fig. 372.—The Johns-Manville Tachometer, a Typical Centrifugal Type. Casing Shown with Dial Removed to Depict Flyweight Governor Design.

able extent. A centrifugal tachometer shows variations in speed from instant to instant, all fluctuations being indicated by the pointer as they occur.

Chronometric Tachometers.—Every chronometric tachometer contains the following essential elements:

(1) A fine toothed pinion or gear, called the "drive pinion," connected to the main shaft and rotating at a speed proportional to that of the engine.

(2) A fine toothed rack travelling on another guide or a fine toothed gear called the "counter."

(3) An escapement mechanism similar to those used in clocks and watches from which this form of speed indicator derives its name "chronometric." Devices of this class can be recognized by the ticking of the escapement.

The drive pinion is thrown in mesh with the counter in some types while in others, the counter is meshed with the pinion in others. This engagement is maintained for a definite period of time, such as one second. This is done by the escapement independently of the speed at which the drive shaft is turning. The distance through which the counter or toothed rack is moved, or the angle through which the gear is rotated while in mesh with the drive pinion is proportional to the speed of the engine. In

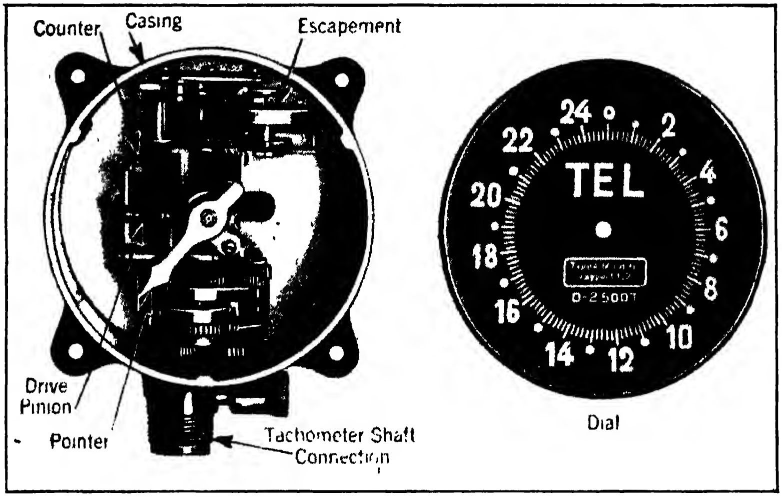


Fig. 373.—The Tel Chronometric Tachometer Showing Mechanism and Dial.

order to have the instrument indicate, it remains only to transform the motion of the counter into a proportionate angular rotation of the pointer on the dial.

Tachometers of the chronometric type such as shown at Fig. 373 indicate variations of speed only at the end of a counting period, therefore, they give a discontinuous reading. If the speed is varying appreciably, even though acceleration be gradual the pointer jumps suddenly from one speed indication to the other.

This is an objectionable feature in adjusting the speed of the motor to any prescribed value, for after the throttle has been adjusted, it is necessary to wait a fraction of a counting period, or a whole counting period, in order to see whether or not the adjustment has been made correctly.

Another common feature of all chronometric tachometers is the method of driving the escapment automatically from the power of the engine to avoid the necessity of winding.

This is accomplished by means of an ordinary spiral clock or watch spring, which is coiled up tightly inside of a flat barrel and which exerts an outward pressure on the side of the barrel. This spring will be referred to as the *drive spring.* Its inner end is fastened to a spindle co-axial with the barrel but passing freely through the same, and geared to the main drive shaft of the instrument. This end of the spring is therefore revolving whenever the instrument is in operation. The outer end of the spring, however, is quite free. When the instrument is started the inner end of the spring begins to revolve and is carried back by the spring to its general or starting position, ready to begin counting again.

The motion of the counter depends, obviously, only on the average speed of revolution during the counting period and does not indicate the way in which the speed varies from instant to instant. For example, an increase in speed during the earlier part of the period might be compensated for easily by a decrease in speed during the latter part of the period, so that if the scale is uniform the reading of the instrument is proportional to the speed.

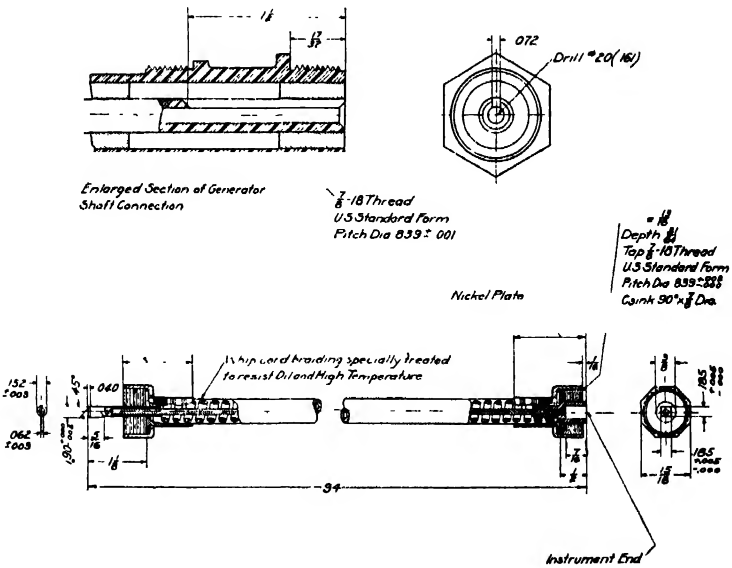


Fig. 374.—Standard Tachometer Drive Shaft and Connections.

Other minor, but necessary operations, enter in. After the counter has finished counting, that is, at the end of the meshing period, it is locked or held and while it is held the indicating train, including the pointer, is released and brought by means of a spring into the position of the counter and locked immediately afterwards in that position. Finally, after this has occurred, the counter is released and the spring winds up, partly around the spindle. A constantly increasing turning force is therefore exerted on the barrel. Finally, however, the other (free) end of the spring begins to slip around inside the barrel. The turning force exerted on the barrel becomes approximately constant and remains so as long as the instrument

is in operation. The barrel is toothed on the outside and is connected through a train of gears to the escapement wheel.

Tachometer Drives.—The tachometer is driven from the engine, most conveniently, by a flexible shaft, as shown in Fig. 374. This, in its simplest form, consists of a very flexible twisted wire enclosed for protection in a casing formed by a braid covered helical spring. This wire is made of a straight core and successive layers of wire are wound around it, alternately left and right. The casing should be oil and moisture proof, light, yet not liable to deterioration by heat and oil. The exact construction of shaft and casing vary, but the outside diameter is about ⅜ inch.

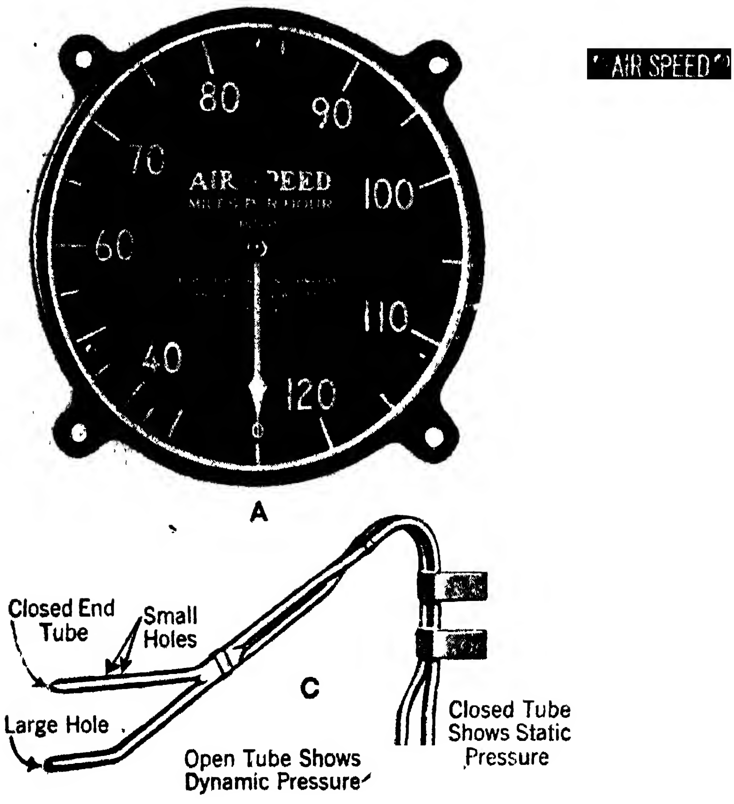


Fig. 375.—Pioneer Air Speed Indicators with Round and Vertical Dials at A and B. The Pitot-Static Tube Used to Operate the Indicators is Shown at C.

The end connections are standard. The engine end is small and cylindrical with a single integral key. This end must be long enough to allow about one inch play for each 6 feet length of shaft. The tachometer end is fixed into a socket with a 3/16 inch square hole. (S. A. E. Standard.) This socket fits over the spindle of the tachometer. The casing has, on either end, a fitting similar to a female hose coupling which is screwed over fixed male ends on the engine and tachometer, thus making the entire shaft oil

tight. The engine must be built with a special tachometer drive shaft which must be drilled and slotted to fit the end of the flexible shaft. The slotted portion must be long enough to allow the required amount of end play. Standard practice is that the tachometer drive shaft shall run at half-crankshaft speed. An error in the instrument of 25 r.p.m. at a speed of 1,500 r.p.m. is considered a large error and instruments should be calibrated from time to time to make sure they are accurate.

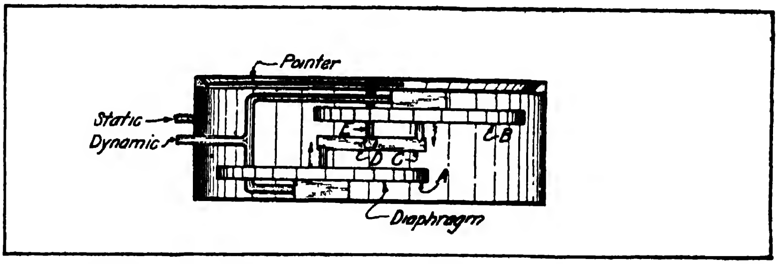


Fig. 376.—Section of British R. A. F. Mark IV Air Speed Indicator Gauge.

Air Speed Indicator—An air speed indicator is a sensitive pressure gauge, which is adapted to indicate in terms of air speed (at sea level) by the use of a pitot-static head which accurately resolves the air speed into its equivalent pressure. The pitot-static tube consists of two tubes, one of which has an open-end and receives the full impact of the moving air. The other tube is closed at its end and has small holes or slots some distance back from the end. These transmit to the interior of the tube the static pressure which may be greater or less in value than the pressure in the cockpit where the indicating instrument is located. Some pitot tubes are

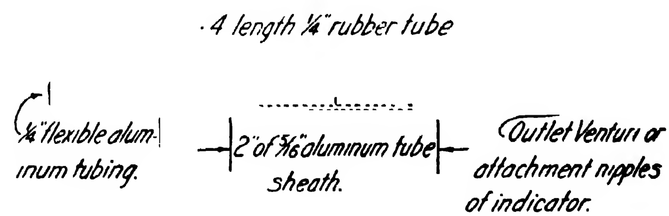


Fig. 377.—Showing Method of Using Rubber Tube to Connect Aluminum Tubing to Venturi or Pitot-Static Heads and Air Speed Meter.

made with the tubes concentric as shown at Fig. 378 so they appear to the eye as one tube, but in all cases, two separate conductors are necessary. The pitot-static tube is installed on the conventional biplane about two-fifths of the distance from the top plane on an outside interplane strut that is clear of the propeller slipstream. On externally braced monoplanes, a suitable place can be found on a bracing strut. When installed on an internally braced monoplane, it is generally necessary to extend the pitot

tube mounting from two to four feet ahead of the wing or from 18 to 24 inches below it to reach a position of undisturbed air.

Pioneer Air Speed Indicators are made in two styles of case and in all ranges from 0-80 to 0-350 miles per hour. The use of a reliable Air Speed Indicator is urged by every pilot of wide experience. It gives a plane a safety factor which cannot be obtained by any structural feature. Every ship has a certain safe flying range of speed, the lower extreme approaching the stalling point, and the higher extreme nearing the condition of a dangerously steep dive. The air speed, for a given engine speed, is therefore an index of the fore-and-aft angle of the airplane. Its use greatly facilitates the maintenance of the correct longitudinal attitude, particularly under conditions of poor visibility.

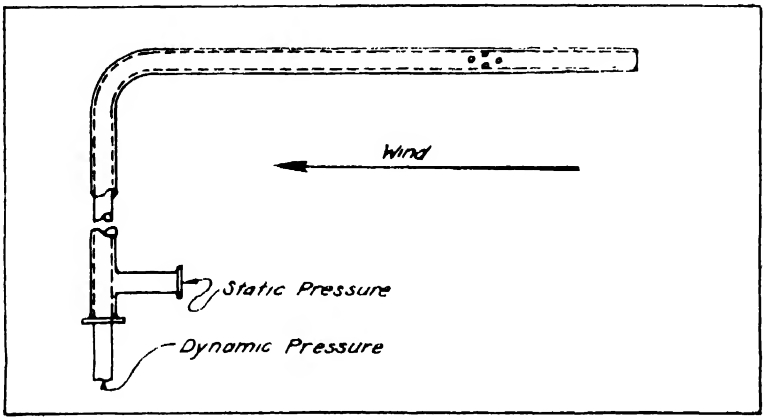


Fig. 378.—Diagram Showing how Concentric Type Pitot-Static Head is Built.

The instrument illustrated at Fig. 375 A is of the well-known round dial type, while that at B is the vertical scale type which is rapidly coming into favor. Vertical scale instruments permit much more compact grouping with consequent saving of instrument board space. This type of indicator is patented, and both the indicators and the pitot-static tube are covered by pending patent applications. The weight of the round type indicator is 0.7 pound, and that of the vertical type 1.2 pounds. The Pitot-Static Tube shown at Fig. 375 C weighs 0.4 pound, and connecting tubing 0.06 pound per foot. It has been the common practice to use short pieces of rubber tubing for joining the connecting tubes to the Pitot and to the Indicator. While this is satisfactory if the rubber tube is replaced regularly as it deteriorates, it is recommended that soldered metal-to-metal fittings be used. Without extra charge both the Indicator and the Pitot Tube are equipped with this type fitting, and two special T's are supplied which may be used both for an intermediate tube connection (as for example at juncture of wing and fuselage) and as drains. In ordering Air Speed Indicators it should be specified if they are to be equipped for rubber or metal connections.

The indicators or gauges of most air speed indicators operate on practically the same principle. The sectional view at Fig. 376 shows the

R. A. F. IV A, a British type. The whole gauge is made airtight by rubber gaskets. Inside are two diaphragms A and B made of thin, very flexible metal. The top of B and the bottom of A are fixed to the case. The movable ends push through small rods to the cross arm C on the spindle D. At the end of this spindle is an arm E that engages a quadrant suitably geared to a pointer, the motion of which is opposed by a light air spring. The dynamic pressure is led to the inside of the diaphragms, the static pressure merely to the inside of the case. The diaphragms tend to expand and the guage is independent of gravity or centrifugal force and entirely free of pressure in the cockpit.

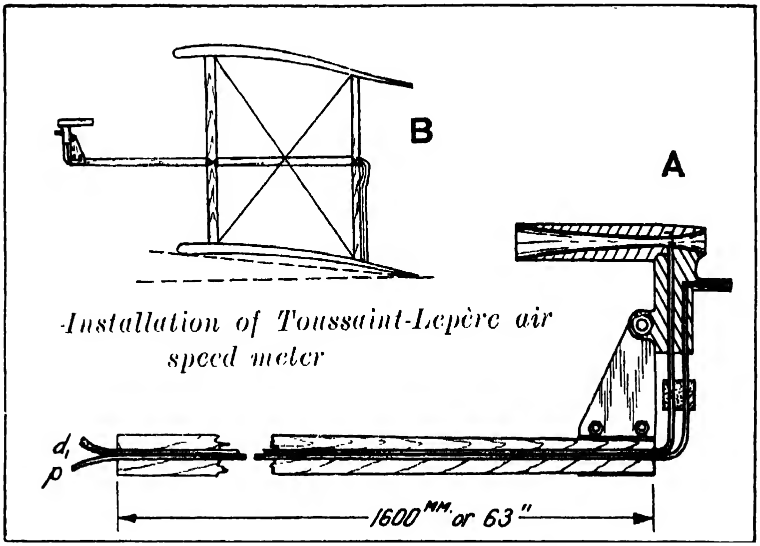


Fig. 379.—Diagram Showing Antenna or Venturi Type Meter for Air Speed and the Supporting Arm at A. Method of Installation in Biplane at B.

The Venturi-Pitot tube is connected with the air speed indicator by flexible aluminum tubing. In using the aluminum tubing sharp bends and kinks must be avoided. It is absolutely necessary that the connections at all joints be airtight. For this reason the following method is recommended for making connections between the aluminum tubing and the outlets of the Venturi, or the nipples of the indicators, or between sections of the tubing. (See Fig. 377.)

(1) Slip a 4 inch length of standard rubber tubing, ¼ inch bore over the 2 inch length of the 5/16 inch diameter aluminum sheath, so that the ends of the rubber tube extend 1 inch beyond the extremeties of the sheath.

(2) Butt the ends of the aluminum tube and the connection, and slide the sheath in the rubber tube over the joint so that the joint comes at the middle of the sheath.

(3) Bind the two ends of rubber tubing with wire. First tie the wire near the sheath with a simple knot, leaving one short end free, which is pressed down along the tube and bound under. The wire is wrapped around the tube and when the wrapping is finished the two ends of the

wire are twisted together and cut off, leaving a ¼ inch stub to prevent slipping. In binding the rubber care should be taken not to cut it.

Recording Air Speed Meter—In testing, it is often desirable to show the air speed in the form of a record that will be made independently of the pilot and that can be preserved for future reference and comparison. The Toussaint-Lepère instrument, shown at Fig. 380 is a typical device of this character. In the Toussaint-Lepère air speed meter the dynamic pressure of the wind is measured by a combination of Pitot tube and Venturi meter. This pressure is transmitted to a clock work recording device by a gauge consisting of bellows and a tension spring.

The Pitot tube and Venturi meter are combined in a small casting conveniently called by the French *antenna* and similar to that of many other speed indicators. This antenna is shown in Fig. 379 A. The Venturi is carefully proportioned to give the maximum possible suction with a given air speed. The antenna is supported by a long, slender, hollow arm of

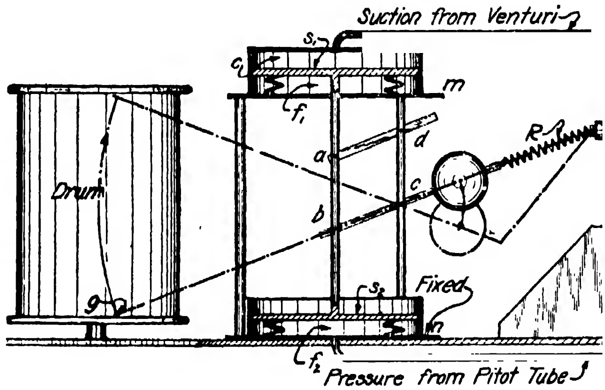


Fig. 380.—Recording Apparatus of the Toussaint-Lepere Air Speed Meter.

light wood which contains the tubes transmitting the pressure to the recording device as shown in Fig. 379 B. It is fastened to this arm by a light, adjustable clip, in order that the antenna may be turned directly into the wind.

The recording device is shown diagrammatically in Fig. 380. It has the ordinary clockwork drum and pen. These are described elsewhere. The gauge consists of two movable circular plates S_1 and S_2, rigidly connected by a rod ab. The plates form the tops of the bellows f_1 and f_2. The sides of these bellows are made of thin rubber that is very flexible, the bottoms are formed by the fixed plates m and n. The suction from the Venturi is led to the airtight chamber c-c, and so acts on top of the plate S_1. The pressure from the Pitot is led to the under side of the plate S_2. The top of S_2 and the bottom of S_1 are open to the air inside of the box. Thus a variation of that pressure causes no motion of the rod ab which is moved only by the difference of the pressure transmitted from the antenna.

The rod ab is constrained to move vertically by the form bar linkage

a-d-c-b. The link bc carries on one end the marking pen g; on the other a counterweight for the movable parts of the instrument. At the end of this link is fastened the spring R, whose tension balances the pressure of the pen. This spring is so placed that the displacement of the pen is nearly proportional to the wind speed. The recording apparatus is enclosed in a box 9 inches by 6 inches by 5 inches, total weight about 4¼ pounds. The apparatus slides out of this box to facilitate adjustment of paper on the drum.

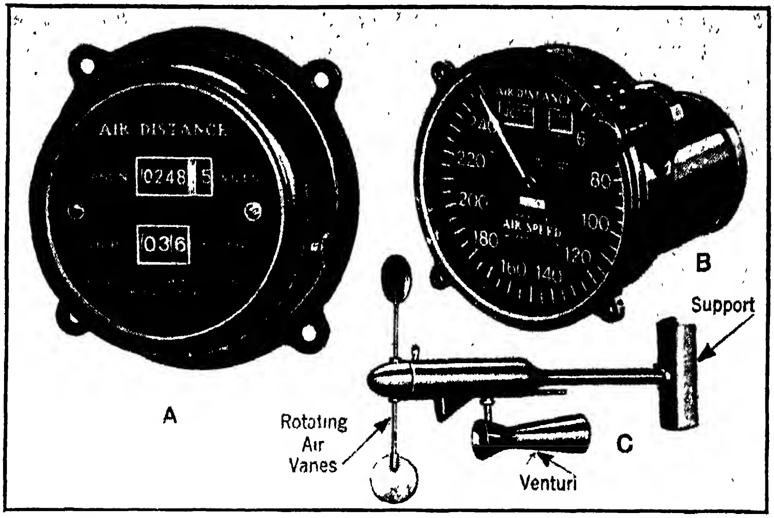


Fig. 381.—Pioneer Air Distance Meter at A. B—Combined Air Distance and Air Speed Meters. C—Operating Head for Air Distance Meter.

The complete speed indicator must be calibrated and a chart or table made for converting the readings on this drum into true wind speeds. This chart of course is only correct for readings in air of standard density. The recording apparatus is suspended in the airplane by elastic cords or may be held by the passenger in a two-seater. The antenna must not be placed near any obstructions or disturbance including the slipstream, body, etc. The supporting arm is fastened to any convenient part of the airplane such as a strut by tape or a fitting. The antenna is then adjusted to point directly into the wind. With this instrument as with all air speed meters, a test run in flight must be made over a measured course to determine the effect of interference of the plane upon the airflow to the antenna, and to find the correction due to this interference.

Approximate Air Speed Correction at Heights.—A very useful table furnished by the Technical Department, British Aircraft Production, allows air speed corrections at heights to be made with fair accuracy, on the assumption of certain standard conditions. Its use is not recommended for the computation of performance results, but may be very handy as a check. The table employs mean value of the density at various altimeter heights. Ground temperature of 16 degrees C. and pressure of 760 mm. are assumed, and a lapse rate of 1.75 degrees C. per 1,000 feet ascent.

Air Speed Indicator Troubles.—It is stated that many air speed gauges are damaged by being blown into or sucked upon under the mistaken notion that it is necessary to exert full lung pressure in testing the gauge. The pressure or suction necessary to secure a speed indication of 120 miles per hour is only six inches of water pressure. An ordinary person can exert a lung pressure of eighty inches of water and can suck about twice as much. Thirty inches of pressure applied to the pitot connection or the same suction applied to the static connection will damage an air speed indicator so it is rendered unfit for use. The following notes on the maintenance of air speed indicators were published by the Pioneer Instrument Company of Brooklyn, N. Y. in "Aviation" and should be of considerable practical value for all airplane operators or mechanics.

Troubles with air speed indicators become apparent in three different ways. First, failure of the hand to return to zero. Second, incorrect speed indication—usually too low. Third, sluggish movement of the hand and failure to respond quickly to changes in speed. The source of the trouble, in any particular case, may lie in the indicator or may be due to leaks or stoppages in the connecting tubes.

TABLE XXIII

Air Speed Corrections at Heights

Apparent speed instrument reading m.p.h.	Corrected Speeds at Heights (m.p.h.)			
	6500 ft.	10000 ft.	15000 ft.	20000 ft.
40	44	46	50	54
45	49	52	56	60
50	65	58	62	67
55	60	63	68	74
60	66	69	75	80
65	71	75	81	87
70	76	81	87	94
75	82	86	93	100
80	87	92	99	107
85	93	98	106	114
90	98	104	112	120
95	104	109	118	127
100	109	115	124	131
105	115	121	130	140
110	120	127	137	147
115	120	132	143	154
120	131	138	140	161
125	137	144	155	107
130	142	150	161	171
135	147	156	168	181
140	153	161	174	187
145	158	167	180	194
150	161	173	186	201
155	169	179	193	207
160	175	181	199	214

Regardless of the difficulty, the first step in locating the source of trouble is to disconnect the tube lines from the indicator. If the trouble was failure of the hand to return to zero, note if the hand comes back when the connections are removed and the instrument tapped gently. If the hand comes to zero, the trouble is in the lines. If the hand does not come to zero, the trouble is in the indicator, which should be removed from the board. One of two things may be wrong. Water may have found its way into the diaphragm, or the diaphragm may have been subjected to excess pressure. Manipulate the indicator so as to let any water run out, if trapped inside. If none appears, and the hand continues to remain off zero, send the instrument to the factory for repairs. If the instrument is of the proper range for the airplane upon which it was mounted, it cannot have been damaged by excess pressure imposed in flight. The usual cause of such damage is to be found in the use of the indicator as a "lung-tester" by a mechanic or receiving clerk. If the hand returned to zero upon disconnection of the lines, the instrument was O.K., and the trouble is due to water in the lines, which should be drained out. Incorrect readings may be due to poor calibration or to mechanical defects in the indicator, but such troubles are so rare they can be dismissed pending the investigation of every other possible source of difficulty.

Low readings are usually due to leaks, and sluggishness to stoppages in the lines. Tests for both are easily made. First, since the instrument is now disconnected, try the indicator itself for leaks, stoppage or friction. Attach a length of rubber tube to the static (S) connection. While carefully watching the hand of the air speed indicator, suck very gently on the end of the rubber tubing until the hand reaches about one-half of the full range, then close the tube by pinching or by putting your tongue over the end. The hand should stand still or return toward zero very slowly. It should not travel over 10 miles in the scale in a shorter time than 30 seconds. If the hand moves faster than this, there is a leak in the case and the instrument should be returned to the factory for repairs. If the movement of the hand is within this limit its approximate rate should be noted.

Now open the rubber tube, and note if the hand drops back quickly to zero. If it does not, there is a stoppage or excess friction in the indicator and it should be returned to the factory for repair. Assuming that the indicator showed no leak in excess of the limit, and that the hand dropped back to zero as it should, proceed to test the tube lines for leaks and stoppages.

Connect the pitot line to the static side of the indicator (where the rubber tube has been during the previous test). Slip the rubber tube over the end of the pitot tube of the pitot-static tube. Have someone watch the dial of the indicator. Suck gently on the rubber tube, having the observer stop you when half scale is reached. Close off the rubber tube, and have observer note if the indicator hand moves toward zero any faster than when the instrument alone was tested. If so, a leak is indicated. Leaks are almost always at joints, although split tubes are occasionally found. By breaking into the line at each joint and retesting, the leak may be located by a process of elimination.

After the line has been made tight it may be tested for stoppages. Suck

on the rubber tube as in testing for leaks, until the hand reaches half-scale indication. Open the tube and note if the hand drops back to zero quickly. If not, a stoppage is indicated. This may be located by breaking into the line and retesting. The same process of testing for leaks and stoppage may be applied to the static line, but as it is impossible to make a direct connection to the static tube of the pitot-static tube, it is necessary to disconnect the line, and to attach the rubber tube directly to the disconnection tube.

Once an air speed indicator installation is properly made, particularly if soldered metal connections are used, it should last for the life of the airplane without any attention beyond the occasional draining of water. If trouble does develop, its source may be quickly located if these directions are carefully followed.

Air Distance Recorder and Speedometer.—Pioneer Air Distance Recorders are now made both for pneumatic and for electric operation. With the electric type is incorporated an indicator of Absolute Air Speed, the combination being known as a Speedometer. The air distance recorder is shown at Fig. 381 A, the electrically operated type is shown at Fig. 381 B. The transmitter for the air distance recorder is shown at Fig. 381 C.

Air Distance is the yard-stick by which the performance of aircraft is measured. If it is known accurately it is possible to express every essential characteristic of a ship in terms which have a substantial and dependable basis. In order to have a record of the performance of his ship, every thorough pilot keeps a "log": noting the time of take-off and landing of every flight, figuring the elapsed time, and totaling, day by day, the flying time. To arrive at the distance he has flown, the best he can do is to multiply his hours by the estimated average air speed—giving a result which is in most cases so far from correct that reliable performance figures cannot be based upon it. And to maintain this record either the pilot or his mechanic has to do a large amount of disagreeable clerical work.

All of this "bookkeeping" and inaccuracy is eliminated by the use of an Air Distance Recorder or Speedometer. If a trip or daily record is wanted, this may be noted from the "trip" indicator which is then set back to zero. The "season" mileage gives a continuous record of the operation of the ship. This provides a real basis for all calculations and records: fuel and oil consumption, actual air speed, service between overhauls, costs per passenger or per ton-mile, relative financial return from different ships per mile flown, etc. These instruments are also valuable for pilots flying over unfamiliar country, or in weather which more or less obscures their landmarks. By making allowance for the wind, which can be done with a simple ground observation, it is possible to bring a ship down pretty close to a desired field, even under most unfavorable conditions. On such a flight a reliable compass is, of course, necessary, and proper allowance must be made for drift.

Both the Air Distance Recorder and the Speedometer are thoroughly reliable and practically "fool-proof" instruments. The Indicator of the pneumatic type is shown at Fig. 381 A, its Transmitter is illustrated at C. In this type a small propeller revolves as the plane goes forward, once a mile actuating a valve which admits vacuum, created by a small but powerful Venturi tube, to an indicator on the instrument board, adding one mile

to the recorded distance. The combined weight of the transmitter and indicator is less than two pounds, and the head-resistance of the transmitter is practically negligible owing to its streamline shape.

Installation Instructions.—Mounting of Transmitter. The Transmitter is mounted on a forward wing strut, far enough from the propeller slipstream to assure its location in undisturbed air. The best position is from one-third to one-half way down from the top plane. If the shape of the strut clamp does not conform to the strut it may be bent to suit.

In ordering, the angle between the strut and the horizontal, in normal flight, should be specified, and the transmitter mounting is then properly adjusted at the factory. The transmitter body should be exactly in line with the normal airflow, and if it does not lie in this position the mounting tube may be bent slightly, or the bracket may be blocked out from the strut.

Mounting of Recorder. Cut a hole in the instrument board to take the recorder case. Screw in place with mounting screws furnished.

Connection. Between the transmitter and the recorder run a length of 3/16 inch diameter metal tube. Make connections at each end with soft rubber tube. Give rubber connections a coat of shellac to prevent corrosion by oil.

Care. Oil transmitter with about 10 drops of "Gun Oil," "Nyoil" or "Nujol" every 500 miles.

Resetting of Trip Mileage. Turn knob forward until the two righthand figures are the same, as for instance, "—44" or "—77." Then pull knob out (about 1/32 inch) and the rings carrying the two right hand figures may be turned forward together until 000 is reached. The knob should be pushed in again *only* when 000 is directly in the *center* of the opening. If they are carried past the center, turn the knob forward until they all come around again. Never try to turn knob backward, or try to force it.

Aneroid Altmeters.—Instruments used to indicate height above sea level are barometers operating by simple physical laws. An aneroid barometer contains one or more nickle silver drums from which the air has been exhausted, a spring serving to hold the opposite faces of each drum apart. The faces separate as the air pressure decreases and come together as it becomes greater. The movement of the spring is transmitted to the index by a system of levers and a chain passing over a small wheel. In the ordinary instrument the movement of the index is proportioned to the change of pressure and if such an instrument is provided with a height scale the intervals for successive thousands of feet are not equal. In an altimeter, the mechanism is devised in such a way that the scale indications are uniformly spaced, which result is obtained by a compensating device in the linkage.

The position of the index depends only on the pressure so that if the scale were fixed and the altimeter was kept at ground level, the change in atmospheric pressure from day to day would be shown as a change in height. An aneroid barometer can be used in two ways. It may be employed as an altimeter for ordinary flying where great accuracy in measuring height is not essential and it may be used as a pressure instrument for accurate testing. When used as an altimeter, an adjustable scale is employed and the pilot sets it at zero at the beginning of a flight. Under such

conditions, the heights are distances above the ground at the point where the altimeter is set and not distances above sea level.

Altimeters do not give absolutely dependable indications at all times as lag or hysterisis or lack of compensation for changes in the temperature of the instrument will introduce errors. After being used at low pressure or at heights for some time it will indicate less than the correct pressure or more than the correct height and gradually recover. The extent of hysterisis depends on the quality of the metal used for the aneroid box. An altimeter may be regarded as fairly satisfactory if after an ascent and descent of 20,000 feet at the rate of 1,000 feet per minute the error on account of lag does not exceed 150 feet. The existence of this source of error must be borne in mind when the behavior of the altimeter is under discussion. The same reading on the ascent and on the descent has different corrections; in general the altimeter reading is too low during the ascent, and too high during the descent. With the improvement of the steel aneroid boxes this

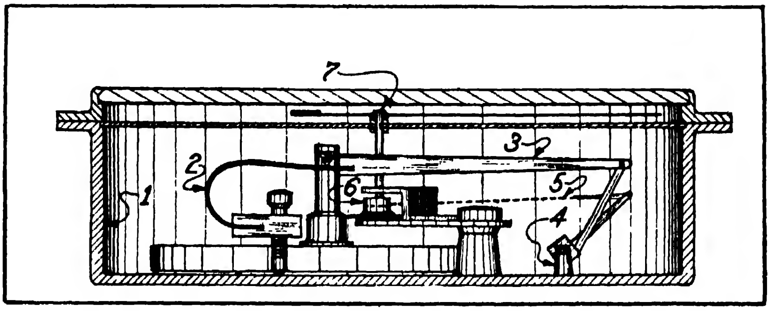


Fig. 382.—Diagram of Working Mechanism of an Aneroid Altimeter.

defect may be eventually eliminated. The vibration on an airplane may make the pointer of an altimeter unsteady. The mechanism is usually balanced by the use of a pair of boxes carefully selected to work together. An altimeter may be tested for lack of balance by reading it face up or down.

A device to compensate for its own temperature is generally used in a modern instrument. Its readings are not appreciably affected by changes in its own temperature, and as long as the pressure remains constant the index will not move. This compensation for the loss of elasticity of the aneroid when heated is effected either by leaving a little air in the exhausted box or by introducing a bi-metallic arm in the magnifying mechanism.

But the most serious error in the aneroid barometer in estimating height is that the difference in pressure between any two levels depends on the temperature of the intervening layer of air. The scale of the altimeter may be graduated for some definite temperature, supposed to be the same at all heights, or for some definite surface temperature, and a given rate of decrease of temperature, with increase of height. It is the usual practice to adopt the uniform temperature 50 degrees fahrenheit in all commercial instruments.

Principles of Aneroid Altimeter.—Fig. 382 is a diagram of the interior of an aneroid altimeter. The aneroid box (1) is an airtight chamber from

which the air has been exhausted. The top and bottom diaphragms are circular in shape and corrugated, and are made of nickle silver. As the exterior pressure is decreased the diaphragms are drawn apart by the steel spring (2), as the atmospheric pressure increases the diaphragms are pressed together against the action of the spring. In order to describe the operation of the mechanism suppose the airplane to be climbing. The pressure of the atmosphere is decreasing and the diaphragms are drawn apart, the main spring (2) relaxes, the edge to which the arm (3) is attached rises lifting the arm with it. This motion is communicated to the spindle (4) through a link rod. To this spindle is fastened a small arm attached to one end of a chain (5). The other end of the chain is fastened to the drum (6). As the arm (3) is raised the spindle is revolved and the chain arm is carried anti-clockwise through a small arc. This permits the chain to be wound in the drum by a fine hair spring under the drum. The drum is fastened to

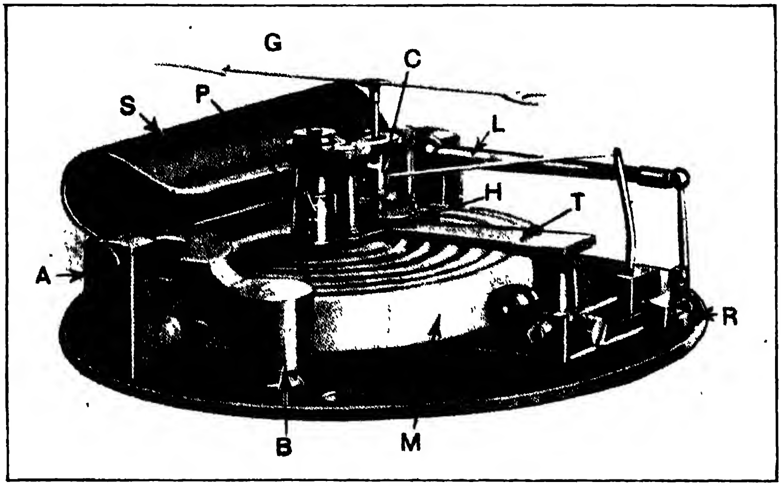


Fig. 383.—Standard Type of Aneroid Barometer with Cover Removed.

the needle (7) spindle, and as the drum revolves the needle point moves round on the dial, indicating the altitude, corresponding to the atmospheric pressure. Ordinarily the scale of altitude would not be graduated in equal intervals for successive thousands of feet, but in altimeters the mechanism is so arranged that the divisions are equal.

Fig. 383 is an illustration of a standard aneroid barometer with cover removed. The mechanism is practically the same as that in the aneroid altimeter used in airplanes. M is a corrugated expansion chamber from which the air has been exhausted. This expands or contracts with changes in atmospheric pressure, and is regulated by the leaf spring S. The latter is mounted on pivots A and fitted with a compensator B to equalize to some extent the expansion of the upper and lower sections of the spring S. The lever L is connected to the opposite end of the leaf spring S. As the expansion chamber M expands or contracts its motion is transmitted to the spring S and through the latter to the lever L. This is connected by a system of small levers R and a very fine chain to the drum C on the spindle of

the indicating pointer or needle G. An enclosed hair spring, shown at H in Fig. 383, tends to turn the pointer G in the opposite direction to the chain attached to the drum C, and thus keeps the chain under a very light tension at all times. A suitable dial (not shown in the illustration) is mounted under the needle G. This dial may be marked in several ways, to indicate atmospheric pressure, altitude, or to predict weather changes, etc. Trouble sometimes is experienced with the fine connecting chain, which may kink or break where it winds on the drum C.

Calibration of Aneroid Altimeters.—The altimeter to be calibrated is placed in a metal pan which has a heavy glass covering, resting on a rubber gasket. The pan is connected to a mercury column gauge by an airtight

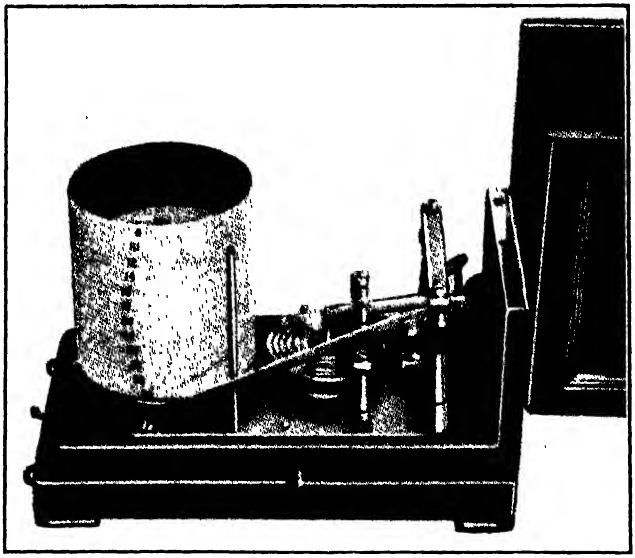


Fig. 384.—Widely Used Type of Recording Aneroid Altimeter Known as the Barograph.

connection. The pressure is decreased by regular intervals at a temperature of 10 degrees C., and simultaneous readings of the mercury gauge are taken. This is continued until the greatest height of the instrument has been reached. Then the pressure is increased in the same way until ground pressure is reached. The variation from the correct indication due to drag is limited by the Army Air Service spècifications. The height corresponding to the observed height of the column of mercury is computed from the formula $H = 62{,}900 \log_{10} \dfrac{P_0}{P}$ based on a temperature of 10 degrees C.; a curve of this is given in Fig. 385.

To determine whether the instrument is affected by temperature the above test is repeated at temperature of —10 degrees C. and +40 degrees C. The errors must be within certain limits also in accordance with specifications. The Bureau of Standards carries out a great number of these calibrations.

Barographs.—The barograph is merely a recording altimeter. The principle of operation is the same. Instead of having the movement of the aneroid box transferred to a pointer which indicates the altitude on a graduated dial, in the barograph the movement of the aneroid box actuates a pen which marks the altitude on a chart wound around a drum. The drum is revolved by clockwork inside and the pen draws an actual curve of altitude against time on the chart. The mechanism is clearly shown at Fig. 384.

The instrument is very delicate and must be suspended in the cockpit of the airplane by elastic cords in order to take up any sudden shocks due to landing or starting.

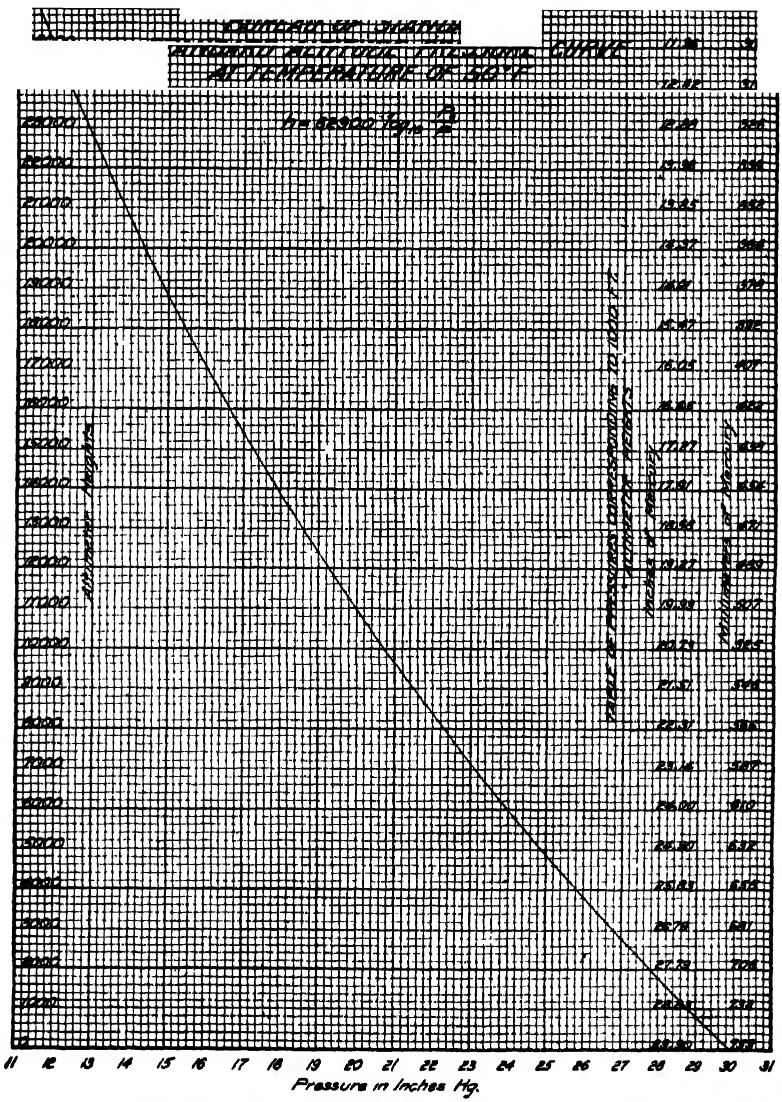


Fig. 385.—Chart Showing Relation between Altitude and Pressure at 50 Degrees Fahrenheit or 10 Degrees Centigrade.

the indicating pointer or needle G. An enclosed hair spring, shown at H in Fig. 383, tends to turn the pointer G in the opposite direction to the chain attached to the drum C, and thus keeps the chain under a very light tension at all times. A suitable dial (not shown in the illustration) is mounted under the needle G. This dial may be marked in several ways, to indicate atmospheric pressure, altitude, or to predict weather changes, etc. Trouble sometimes is experienced with the fine connecting chain, which may kink or break where it winds on the drum C.

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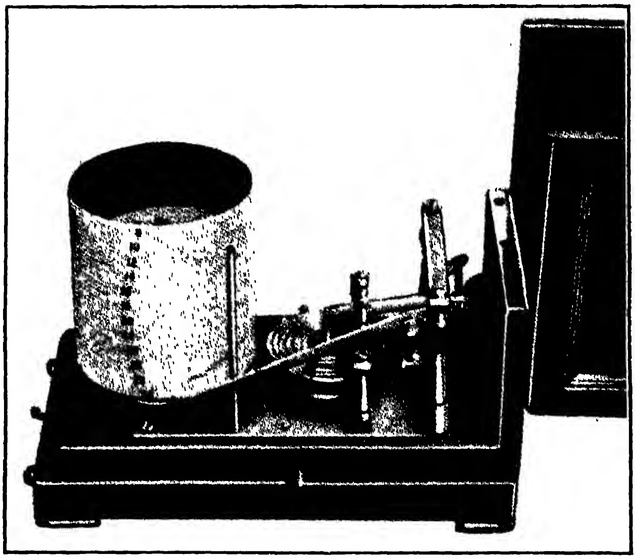

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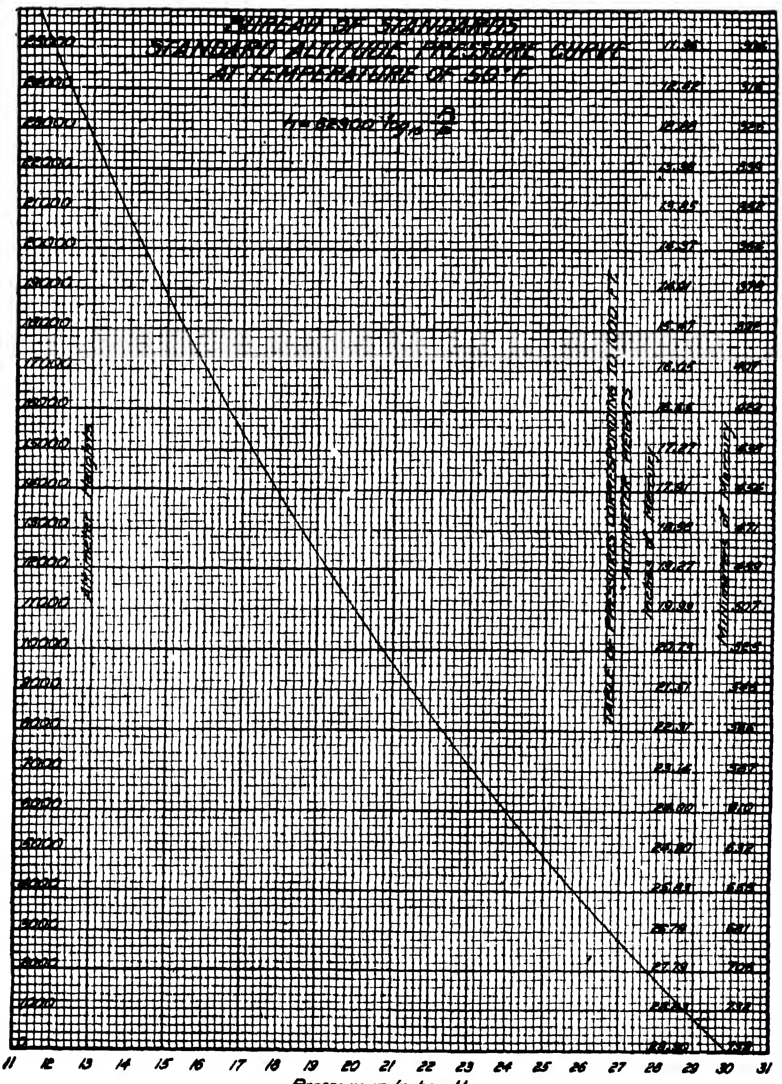

Fig. 385.—Chart Showing Relation between Altitude and Pressure at 50 Degrees Fahrenheit or 10 Degrees Centigrade.

Alignment Chart for Altitudes.—An alignment chart is given at Fig. 386 for altitude based on the formula $H = 62.900 \log_{10} \frac{P_0}{P}$ at an isothermal temperature of 10 degrees C. or 50 degrees F. and the temperature correction of $\frac{273 + T}{283}$.

This chart is absolutely true for high altitudes when the correction temperature is constant throughout. It is approximately true if the mean temperature between the two altitudes is found. It is almost exactly true if differences of altitude are sought and these differences are small. To use the chart it is only necessary to lay a straightedge across it diagonally,

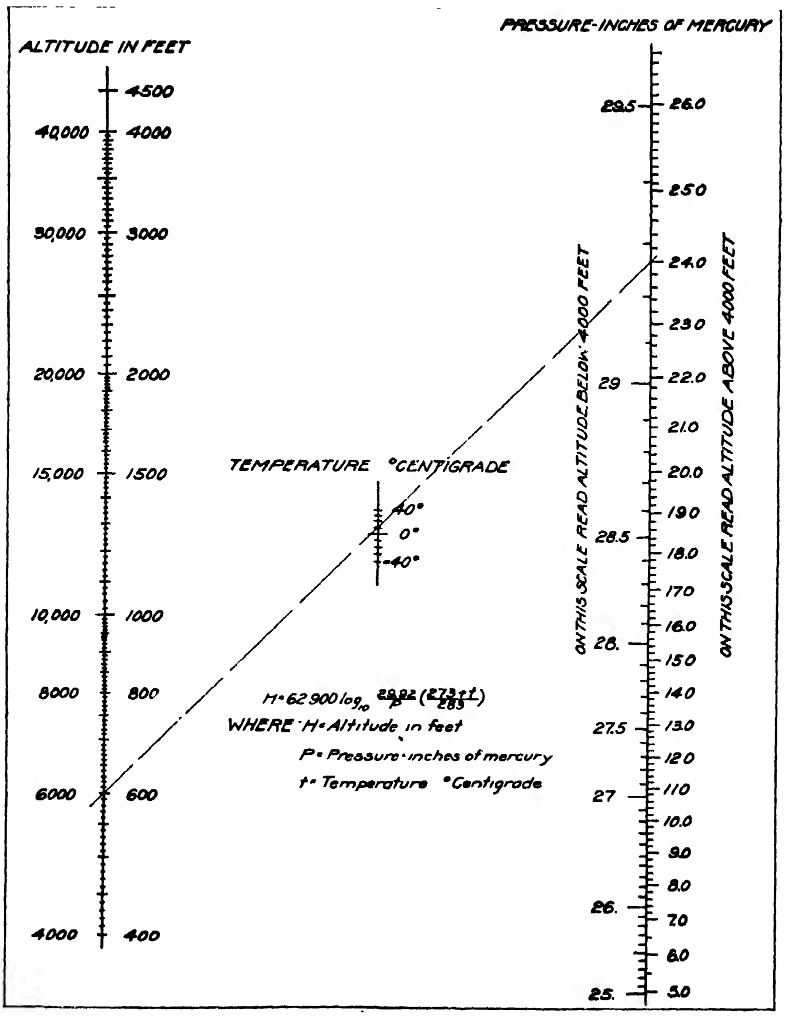

Fig. 386.—Alignment Chart for Altitude and Temperature Corrections. Used for Approximations by Engineering Division, U. S. Army Air Corps.

through the correct pressure and temperature points, the reading where the straightedge crosses the altitude scale is the corresponding height. The scales are graduated on both sides so that a range of altitude from 400 to 40,000 feet can be read. The pressure scale is also graduated on both sides to correspond with the altitude scale. It is necessary to remember, when using the chart, that whenever the pressure lies on the inside scale, the correct altitude will be found on the inside scale also. Another useful conversion chart for changing centrigrade to farenheit degrees is given at Fig. 387. This also gives a conversion from millimeters to inches and vice versa.

Rate of Climb Indicator.—Rate of climb indicators, as shown at Fig. 388 are practical and useful instruments. They consist of a metal case which is sealed except for a capillary "leak tube" within which is placed a sensitive diaphragm cell, the interior of which is connected to the atmosphere. A gear and sector mechanism transmits movements of the dia-

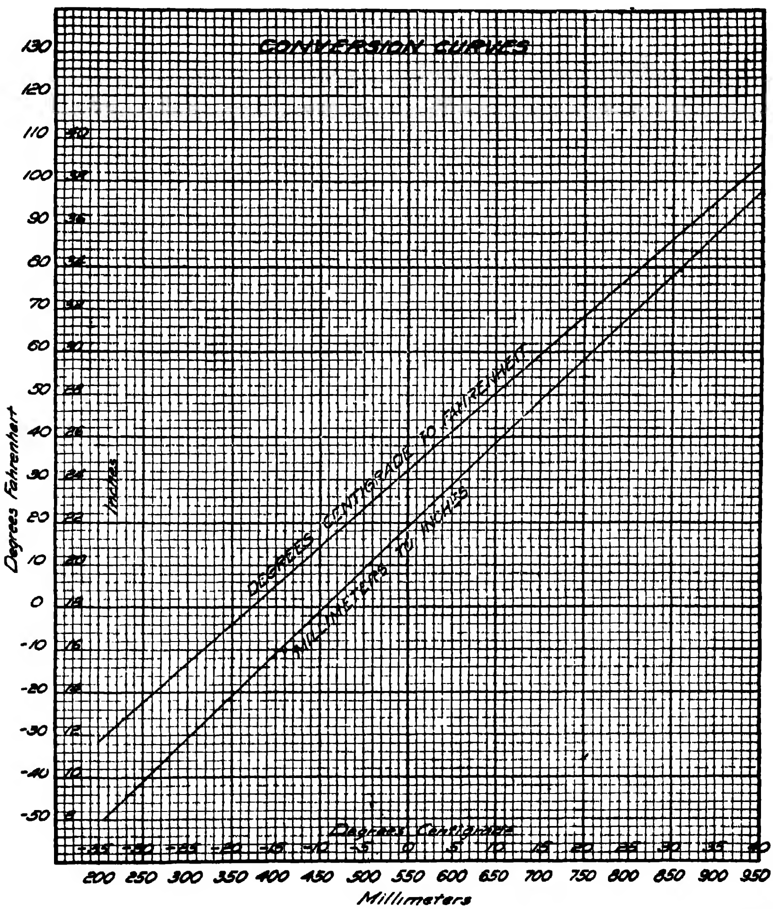

Fig. 387.—Bureau of Standard Conversion Curves for Converting Degrees Centigrade to Fahrenheit and Millimeters to Inches and Vice Versa.

phragm to the indicator pointer or hand. As the aircraft climbs or descends the pressure inside the diaphragm changes instantly while that inside the case changes slowly as the air leaks through the capillary. This applies a pressure on the diaphragm proportional to the rate of climb and the hand is moved accordingly. The instrument is mounted in the same manner as an alitimeter or air speed indicator and as it is self-contained no connections or attachments of any kind are required. The weight of the round dial type is 1.4 pounds, in the vertical scale type it is 1.1 pounds. Climb or descent can be detected much more quickly with this instrument than with an altimeter.

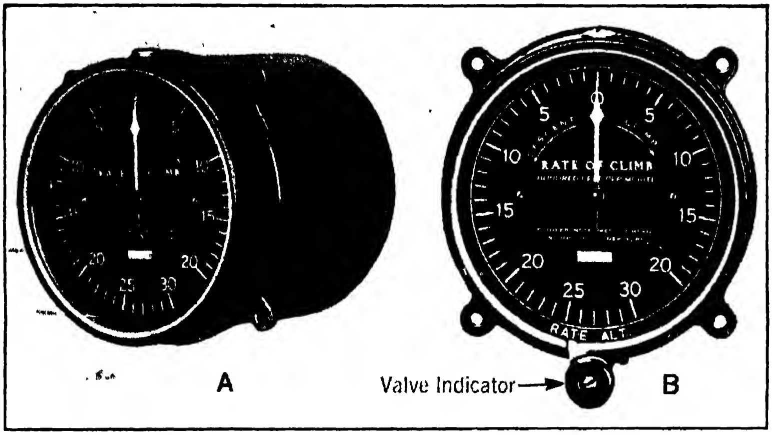

Fig. 388.—Pioneer Rate of Climb Indicators. A—Type 165B Indicates Only Rate-of-Climb. B—Type 165C may be Used as Altimeter by Turning Valve Indicator to Right.

In order to secure the maximum performance from his airplane it is essential for the pilot to know at all times the rate at which he is climbing or descending. This information, supplied continuously and accurately by the Rate of Climb Indicator, makes it possible for him to climb the ship at the highest possible rate or descend as slowly as possible, without danger of stalling. The usefulness of this instrument is not limited to demonstrations or special flights, where it always assures a better performance than the cleverest pilot can attain without its assistance, but extends to any aircraft operated under conditions where flying efficiency is of interest or importance. With its aid a pilot can take a perfectly strange ship and secure the maximum possible performance under any existing conditions, entirely independent of speed, power, or loading—something which is otherwise so difficult as to be practically impossible.

The rate of climb indicator is direct reading and accurate for all conditions. It is not necessary to make any corrections or allowances. Unlike an Altimeter its indications do not vary with the elevation, but read directly in terms of rate of change of altitude. In other words, it shows the vertical component of the speed of the aircraft. It is equally suitable for airplanes or balloons. The instrument illustrated at Fig. 388 A is the Pioneer type 165B which has a range of 2,000 feet per minute climb and 3,000

feet per minute descent. This type is also made with a greater range, reading to 5,000 feet per minute in both directions and being so constructed that it will withstand any rate of descent without damage.

Especially for use on airplanes engaged in aerial mapping an ultra-sensitive altimeter is combined with the rate of climb indicator by providing a valve for closing the capillary tube. This combination instrument is illustrated at Fig. 388 B, and is known as type 165C. It is used as a rate of climb indicator while ascending to the altitude at which it is planned to take pictures, the valve-indicator being turned to the left. Having reached the desired height, the valve is turned to the right and the instrument begins to function as an altimeter, showing elevations above or below the height selected. Operating as an altimeter one scale division corresponds to about 10 feet change in elevation. The valve should be returned to the RATE position before the descent is begun, but the instrument is so constructed that it will not be damaged if this is forgotten.

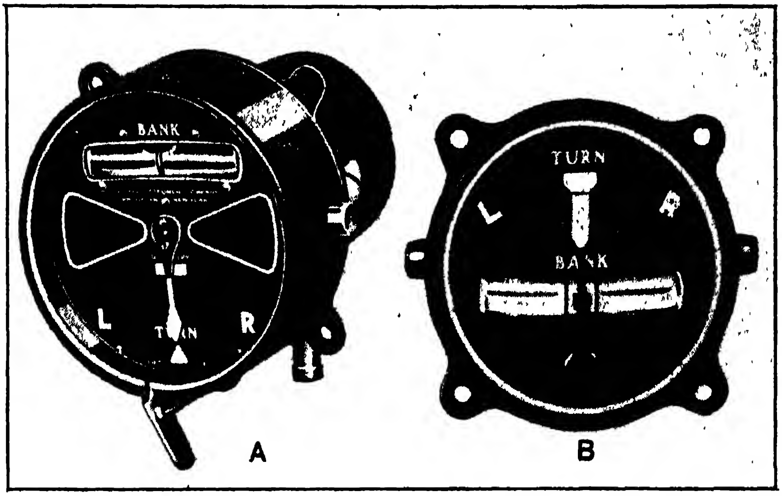

Fig. 389.—Pioneer Turn and Bank Indicators. A—Form Having Shutters as Well as Indicating Hand. B—Type Having Indicating Hand Only.

Securing maximum performance of a plane by the aid of the rate of climb indicator is a very simple matter. To climb as fast as possible, pull in the control until the hand of the indicator will not go any higher. There is a certain range in position of the control where no change will be noted in the indication. Keep the control as far forward as possible without decreasing this indicated rate of ascent. This will assure maximum climb without the possibility of stalling. Similarly for descending without power at the slowest possible rate, it will be found that there is a certain range of control position throughout which no change is noted in the reading of the rate of climb indicator. Keep the control as far forward as possible without increasing this descent indication. This assures a minimum loss of altitude without the possibility of stalling the plane. The rate of climb indicator is also of great help in maintaining the desired altitude in ordinary cross-country flying, when visibility is poor.

Turn and Bank Indicator.—The turn indicator has been developed to its present state of efficiency and reliability through the combined efforts of the Sperry Gyroscope Company, the Lawrence Sperry Aircraft Company and the Pioneer Instrument Company. The Pioneer turn indicator is used for controlling the flight of aircraft under conditions of poor visibility, or when for any reason it is desirable to eliminate yawing or turning. Used in conjunction with the bank indicator, which is built into the dial of all Turn Indicators, the pilot is able to maintain a laterally level attitude while flying straight and to bank at the proper angle when turning. A compass, by itself, is of little value when flying in clouds or at night, as it is practically impossible for a pilot to hold his ship on a straight course, and a compass will only indicate correctly during straight flight or on very slow turns. By using a turn indicator, which shows the slightest divergence from straight flight, the pilot avoids turning, and his compass will function properly. A straight course is maintained by steering so as to keep the indicator in the central position. By keeping the ball or bubble in the center of its tube the aircraft is held laterally level when flying straight, or on the correct bank when turning.

The sensitive element of the turn indicating mechanism is a small air-driven gyroscope, operated by the vacuum secured from a Venturi tube. The gyro is mounted in such a way that it reacts only to motion about a vertical axis, being unaffected by rolling or pitching. Constructional details of the Pioneer turn indicator have been worked out very carefully. The whole instrument is non-magnetic, permitting it to be used close to the compass. Adjustment of sensitiveness may be made to suit any flying conditions. The gyro runs on specially designed precision ball bearings, to which oil is supplied from a reservoir within the gyro. Without any sacrifice of sensitiveness the mechanism of the turn indicator is "damped" so that the hand cannot oscillate even under the roughest air conditions.

Three principal models of turn indicator are manufactured. The type 64D, shown at Fig. 389 A, has both a "shutter" and hand. The former serves to attract the pilot's attention in case an unintended turn is made, and the latter is used when it is desired to maintain the heading of the ship very accurately. Type 64E is identical with 64D except that a ball-in-tube level is used for a bank indicator.

In type 103C at Fig. 389 B, the turn indication is given by a normally upright hand, and a ball-in-tube bank indicator is used. Two sizes of Venturi tubes are made. Type V3C is designed for air speeds under 75 miles per hour and Type V74 is used on airplanes flying at higher speeds. It has been common practice to use short pieces of rubber tubing for joining the connecting tube to the Venturi and to the indicator. While this is satisfactory if the rubber tube is replaced regularly as it deteriorates, soldered metal-to-metal fittings are recommended. Without extra charge both Venturi tubes and the 103C turn indicator are equipped with this type of fitting.

To assure satisfactory operation the following instructions should be closely observed:

Installation of Venturi Tube. The Venturi tube should be mounted on the side or top of the fuselage or upon a strut, as close as is convenient to

the instrument board. It must be placed in a position where it receives an unobstructed flow of air. It is advisable in some installations, particularly on night flying aircraft, to mount the tube in the slipstream to insure that the indicator will be in full operation before taking off. Mount the tube so that the arrow on the name plate points forward.

Installation of Indicator. A hole is cut in the instrument board, and the indicator fastened securely in place, as in the mounting of any other instrument, such as the Air Speed Indicator or Altimeter. The indicator should be mounted on the instrument board so that the dial is vertical, and the ball or bubble in the center of the tube, when the aircraft is in flying position.

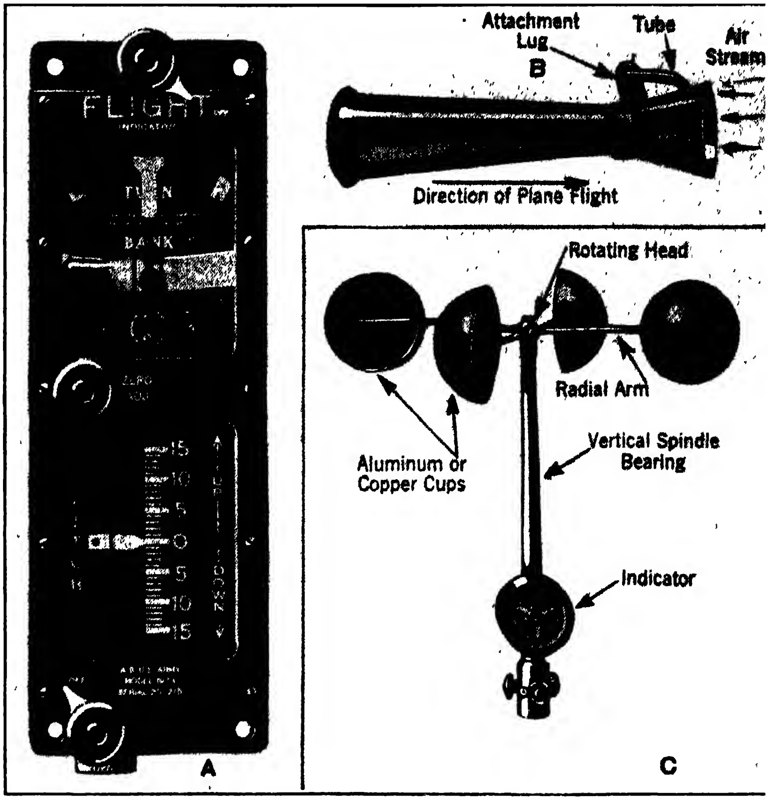

Fig. 390.—Pioneer Flight Indicator at A Combines Turn and Bank Indicator and Pitch Indicator. B—Venturi Power Tube Used with Flight Indicator. C—Anemometer, a Wind Speed or Air Distance Indicator, Depending on how it is Used.

Connecting Tubing. For connecting from the Venturi tube to the Indicator a length of metal tubing should be used. The same precautions to secure airtight joints should be used as in all pneumatically operated instruments.

Flight Indicator.—In the Pioneer flight indicator shown at Fig. 390 A are combined a turn indicator, a bank indicator, and a gyroscopically controlled fore-and-aft inclinometer or pitch indicator. This instrument is used in preference to a bank and turn indicator under conditions where the air-

plane must be held as closely as possible to an accurate level, both fore-and-aft and laterally, as for example in aerial photographic mapping. So long as the airplane does not turn, the bank indicator may be used as an accurate inclinometer. It is therefore only necessary to keep the turn indicator hand on zero and to hold the bank indicator ball in the center of its tube, to maintain the lateral level. The pitch indicator differs from ordinary fore-and-aft inclinometers in its response to changes in longitudinal attitude. While fore-and-aft accelerations have the effect of minimizing the indication of most inclinometers, a gyroscope is combined with this indicator in such a way that the angular accelerations of pitching tend to magnify the indication. So long as the airplane is not changing its longitudinal attitude the fore-and-aft angle is accurately indicated, but if the plane starts to pitch, the hand immediately moves up or down, thus permitting the pilot to counteract the pitching movement before the airplane has appreciably changed its angle. With this instrument the flying attitude of an airplane can be maintained with very great accuracy. The flight indicator is operated from a type V3C Venturi tube shown at Fig. 390 B, this Venturi being used on all types of airplanes. The weight of the flight indicator is 2.85 pounds, and that of the Venturi tube 0.6 pounds.

The following instructions should be closely observed.

INSTALLATION: The Venturi tube should be mounted on the side or top of the fuselage or upon a strut, as close as is convenient to the instrument board. It must be placed in a position where it receives an unobstructed flow of air. It is advisable in some installations, particularly on night flying aircraft, to mount the tube in the slipstream to insure that the indicator will be in full operation before taking off. Mount the tube so that the arrow on the name plate points forward. The same instructions previously given for mounting the turn and bank indicator apply to this instrument as well. The tubing should be 3/16 inch inside diameter if the distance from the Venturi to the indicator is less than eight feet. If more than that, ¼ inch inside diameter tubing should be used. Care should be used to have joints airtight. Before connecting tubing it should be blown clear of all dirt. Avoid bends of small radius and run tubing as straight as possible. Valves operated by knobs at the bezel permit the suction to be varied, thus controlling the speed of the gyroscopes. They are also used for shutting off the instrument when the pilot does not choose to use it.

Anemometers.—The instrument used for measuring the velocity of the wind is called an anemometer and modifications of this instrument have been used to indicate air speed of airplanes and dirigibles. The type which has been found most satisfactory by the U. S. Weather Bureau for its meteorological stations is shown in Fig. 390 C and consists of 4 hemispherical cups, made of thin aluminum or copper, fastened on the ends of 4 horizontal arms at right angles to each other, mounted on a vertical spindle.

The motion of the cups is transferred, by a suitable system of gearing, to a pair of dial wheels graduated to read the velocity of the wind in miles and tenths of miles. In the Robinson anemometer 500 revolutions of the cups represent an actual travel of the wind past the instrument of 1 mile. The outer dial is graduated into 100 divisions, each division corresponds to 1/10 mile of wind travel. For every complete revolution of the outer dial

(10 miles) the inner dial moves one division. In order to determine the velocity of the wind from the dial it is necessary to note the number of graduations through which the dial turns in a measured period of time. If the dial has passed through 10 divisions in 5 minutes the wind velocity is $\frac{10}{10} \div \frac{5}{60} = 12$ m.p.h.

As the anemometer is usually mounted on a tower it is convenient to have the direct reading dial or recording apparatus at some distance from the anemometer. For this purpose the anemometer is arranged to be connected up with dry cells and register electrically. At each of the 1 mile points on the outer dial (i.e., every 10 divisions) small contact pins are set into the dial.

Two of the pins are joined together forming the tenth-mile pin or bridge-pin. A contact spring, one end of which is free and tipped on one side with platinum can contact with a pin also tipped with platinum. This pin is insulated so that it does not come into electrical contact with any metal part of the anemometer. A small wire protected by the metal tube connects the insulated pin with an insulated binding post.

A second binding post is secured to the metal case thus connecting electrically with the contact spring. The middle position of the contact spring has a small brass piece attached that projects into the path of the dial pins, and as the dial moves, these glide in turn over the projection on the spring causing it to deflect and bring the two platinum surfaces (i.e., on the spring and pin) into contact for a short space of time. By this means the anemometer is made to close the electric circuit, and by the aid of a recording mechanism and drum revolved by clockwork the movement of the dials is recorded electrically on a chart. The tenth-mile pin causes the electric circuit to remain closed the entire time of its passage, thus giving a longer dash on the chart and automatically recording each complete revolution of the dial.

When speed indicators of the anemometer type are used, they must be mounted clear of the slipstream and where no air currents or eddies will interfere with correct indications. Distance type recording dials may be used. The anemometer form will indicate air speeds of relatively low value with greater accuracy than pitot-static tube indicators. They are just the same in principle but smaller and lighter than the type shown.

Magnetic Compass.—For years, mariners have found their way over the ocean by means of the magnetic compass, which is a simple instrument for indicating directions in a horizontal plane and thereby acting as a help for steering the ship. The simplest form of compass would be a magnetized bar or needle of steel, so pivoted that it would be supported at its center in a manner that would permit it to swing around on its pivot. One pole of the magnet will point toward the north magnetic pole of the earth, which is different from the north geographic pole in that they do not coincide, so it is necessary to make certain corrections in magnetic compasses if navigation is in directions based on true north pole rather than magnetic north pole. Compasses may be divided into several types, namely the card magnetic, the inductor magnetic and the gyroscopic. As will be evident, mag-

netic compasses depend upon the magnetism of the earth or flow of lines of terrestial magnetism from one magnetic pole to the other. Magnetic compasses point to the magnetic pole whereas gyroscopic compasses indicate geographical direction. The gyroscopic compass is heavier than the magnetic types so it has received but limited application in aircraft. The simplest form of magnetic compass is the fixed card, rotating needle type so widely used by sportsmen, that can be purchased for a dollar or less. This type is not suitable for either ships or planes because it is affected by any magnetic material in its vicinity and will not give true readings.

The card magnetic compass comprises a graduated card that has a number of parallel magnets so suspended that they are free to assume the direction of the earths magnetic· lines. A fixed reference line, called the "lubber line" is securely fastened to the fixed compass bowl. Two forms of cards are used, the float and non-float. In the former, the magnets are carried by a hollow cylinder supported by a liquid so the weight resting on the pivot is reduced. Non-float types have a card of sufficient lightness so the float is not necessary. The compass shown at Fig. 391 A is a float type, that at B is a non-float type. The cards may have the graduations on a vertical plane, on a horizontal plane, on a card combining both or on an inclined card. The inclined card is easily read so it is favored by American aeronautical engineers and pilots. The graduations are spaced by intervals of from 5 to 10 degrees, depending on the size of the card and the cardinal points of the compass are indicated by the abbreviation letters N—E—S—W.

Card magnets are of tungsten steel, hardened and magnetized. This material is used because of its magnetic retentivity. Magnets are attached directly to the card of a float type so as to be parallel to its north and south diameter . In the non-float type they are attached below the card by wires. In an airplane compass the pivot is attached to the card, the jewel cup to the bowl; a reverse arrangement to that followed in marine compasses, this being a concession to the vibration present in aircraft. The bowl of the compass acts as a container for the liquid used to dampen card movement. It may be cylindrical or hemispherical in form and has a glass cover or sides so the graduations can be read. The liquid, which should be non-freezing is either an alcohol-water mixture or kerosene or similar non-congealing mineral oil. Compensating permanent magnets are provided to neutralize effect of disturbance caused by magnetic materials used in either the fuselage or engine structure. All ferrous materials such as iron, steel or its alloys are magnetic while the bulk of the material used such as wood, fabric, and non-ferrous metals are not magnetic.

The function of a compass is the indication of the direction in which the airplane is heading when flying on a straight course. It does not indicate correctly on turns which are fast enough to require an appreciable banking of the airplane. The errors increase rapidly with the increase in the banking angle, a bank of about 20 degrees being sufficient to completely destroy the function of the compass. This condition is inherent in any compass depending upon the earth's magnetic field for its directive effect and upon gravity for its stabilization.

Because of the errors introduced by turning, the compass cannot be

used to hold the plane on a straight course unless the ground can be watched for a directional reference. Where the ground is not visible a turn indicator must be employed to maintain straight flight. So long as the airplane does not turn, its direction will be accurately indicated by the compass. It must not be assumed, however, that the use of a compass is greatly limited. In service one is not concerned with the compass reading except when flying straight, and under this condition the instrument is completely dependable.

A special type of compass is made for mounting on the underside of the center section of a conventional biplane or upon the ceiling of a cabin airplane. This is shown at Fig. 392 B. This form of compass has proven to be very satisfactory, as it can be mounted far enough from the engine and other steel parts of the airplane so that it is very little affected by them. The large letters and figures make it easy to read even though located several feet from the pilot. Its weight is 2¼ pounds.

Installation and Compensation of Magnetic Compass.—Standard brackets are supplied with compasses so an installation can be made in almost any position. It should be mounted where it can be read easily and located as far as possible from parts of magnetic material. It is advisable to place it on the fore-and-aft center line of the airplane. Where two compasses are mounted on the same airplane, they should be located at least two feet apart. Complete compensation is a long and tedious task. It is ordinarily sufficient to adjust the compass to within one or two degrees of the true magnetic heading on the cardinal points and to make a note of the errors on the other headings for which allowance can be made in setting the course.

A simple method consists in tying a long piece of string to some point on the plane from which an accurate fore-and-aft or lateral sight can be made and hanging a small compass from this in such a way that the string passes over its pivot. By turning the plane and sighting along the string any desired positions can be obtained. Whatever method is used for determining directions, the following procedure is recommended for compensating:

Head the plane approximately North. Note true direction. Compare indicated direction. If they do not agree, place compensating magnets in the athward-ship magnet carrier until the compass indicates correctly. Next head the plane approximately East, and compare readings. If not in agreement, place compensating magnets in the fore-and-aft tube until the compass indicates correctly. Repeat on South and West headings. If compensation is required on either of these headings it will of course throw out the compass on the opposite heading. Only half the error, therefore, should be removed. This will leave the errors at opposite headings approximately equal.

Now swing the ship to at least four intermediate headings, and note the errors. Enter these figures on a card and tack up near the compass.

The compass should require little attention beyond periodic rechecking of its compensation. Bubbles, which will appear occasionally, are easily removed as follows: Remove the compass from its bracket. Remove filling-cap (either one) with a screw driver. Hold compass with filling hole

uppermost while doing this. Manipulate compass until bubble comes just below filling hole and drop in kerosene with a medicine dropper or fountain pen filler until it overflows. Replace plug, screw up tightly and reinstall the compass.

TYPICAL CHART OF COMPASS CORRECTION

True Heading	Indicated Heading
0	0
45	48
90	90
135	133
180	180
225	228
270	270
315	312

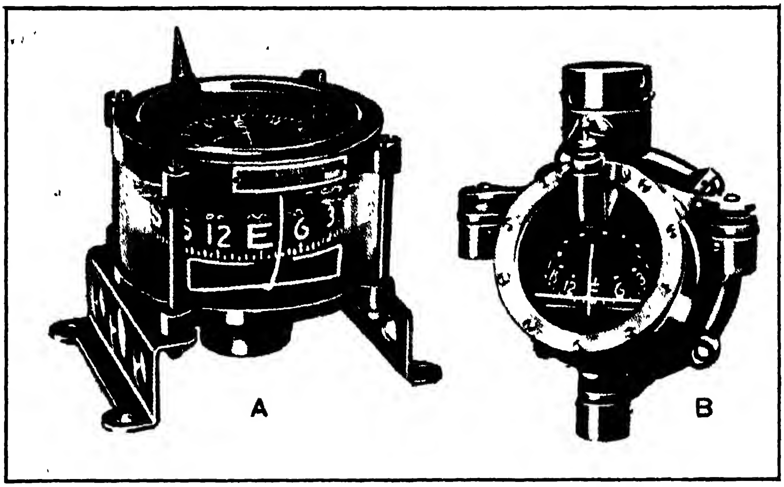

Fig. 391.—Float Type Card Magnetic Compass at A and Non-Float Form at B are Typical Aircraft Instruments.

Earth Induction Magnetic Compass.—Mr. George P. Luckey, while Chief of the Instrument Branch, Engineering Division, Air Service addressed members of the A. S. M. E. and S. A. E. at McCook Field, Dayton, Ohio on the subject of the earth induction compass and the following abstract from his discourse covers the subject so thoroughly that it is reproduced for the information of our readers:

"As ordinarily used on the ground, a magnetic compass is an accurate instrument; but such a compass mounted on a vibrating board located within a few feet of several hundred pounds of iron and subjected to rapid accelerations would give indications of little value. An airplane compass must be visible to the pilot; that is, mounted in front of him. But here it is influenced by the engine, by current-bearing wires and machine guns in front, and perhaps by several thousand pounds of bombs in steel shells beneath or behind it. To have the compass card level, its mass must be unbalanced to counteract the tendency of the north-seeking ends of the magnet to point downward; but this subjects the instrument to error due to accel-

eration caused by airplane vibrations, oscillations and turns. A magnetic compass also requires a certain time to assume the correct reading after a turn of the airplane has been made, because of its oscillation period. In spite of these difficulties, the magnetic compass would give fairly reliable indications when flying straight and level were it not for the fact that the magnetic disturbance due to the presence of the large mass of iron is continually changing because of the effect of vibration and the change in the effect of the earth's field on different headings. If it were possible to place the compass where disturbances due to the earth's magnetic field were small, good results could be obtained; but, in such a position, it would not be visible to the pilot.

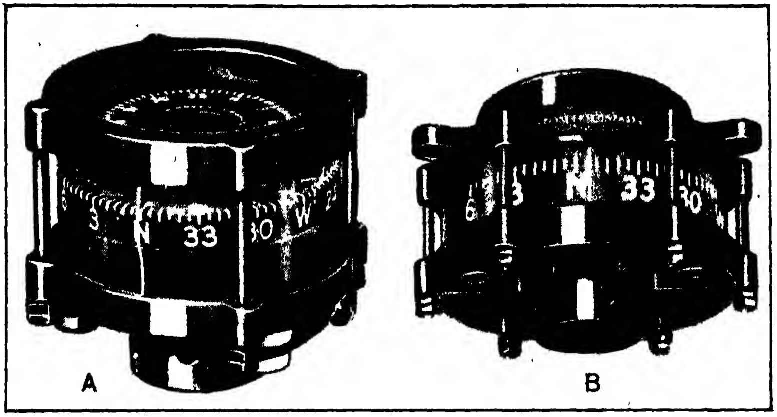

Fig. 392.—Pioneer Card Magnetic Compasses. A—Form that can be Read from Top or Side. B—Type Adapted for Hanging to Ceiling of Cabin or Center Section Top Wing at B Gives Side Readings Only.

Optical systems for reading a compass from a distant location have been tried, but they were found to be impracticable. A distant-reading magnetic compass that employs a selenium cell as a means of transmitting the compass indication to a distance was built by Carl Hamberg, of Germany, but tests did not give satisfactory results. Work on the development of a distant-reading compass was begun in 1920 by the Bureau of Standards, funds being apportioned by the engineering division of the Air Service, and the first satisfactory working model of an induction type of compass was completed and tested in 1921. In spite of the great amount of development work already done on the induction type of compass, much remains to be done; but present models are greatly superior to the magnetic compass in all respects except that of durability."

In a magnetic compass a magnet is allowed to align itself with the magnetic lines of force of the earth, but in an induction compass a current is generated by rotating coils of wire in the earth's magnetic field and the direction of the field is determined by the amount of current generated at any instant in the various coils. To date, two types of induction compass have been developed, a single-circuit and a two-circuit type. In the single-circuit type, a drum-wound armature equipped with a commutator similar

to that used in a direct current generator is rotated in the earth's field. This coil is placed where the magnetic disturbance is minimum and is rotated by a small propeller inserted in the airstream. The current generated is carried to a small galvanometer placed in front of the pilot. The brushes are then rotated so that they are in contact through the commutator with a coil of wire in which no current is being generated and, from the position of the brushes, the direction of the earth's lines of force can be determined. The position of the brushes with reference to the axis of the aircraft will then give the direction in which the aircraft is heading. In practice, the brushes are rotated by a controller as shown at Fig. 366 placed on the instrument board, by a rod connected to the generator. The controller is marked so that, when it is set to have no deflection of the galvanometer pointer, the course on which the aircraft is headed can be read directly. If the aircraft is turned to the right, current will flow through the galvanometer and the pointer will move to the right; for turns to the left, the current generated will be in the opposite direction and the pointer will move to the left.

In the two-circuit type of induction compass two sets of stationary brushes are placed 90 degrees apart. The current from the four brushes is carried to the four corners of a Wheatstone bridge placed on the instrument board. By means of a rotating arm that makes contact with the bridge, current can be carried from any two opposite points to a galvanometer. The arm is rotated until no current is flowing through the galvanometer, and the heading of the aircraft can be read directly from a dial. The generator is hung in a manner similar to that of a pendulum, and the gyroscopic action of the rotating armature tends to stabilize it so that its axis remains vertical during slight oscillations of the aircraft.

The induction compass has many advantages over the magnetic type of compass. It has an accuracy of 1.5 degrees, compared with the 5-degree limit of accuracy of the present airplane magnetic compass. In many airplanes, it is impossible to place a magnetic compass so that it will give readings that are even approximately correct. Since it can be read at a distant point, an induction compass can be placed where it is undisturbed by local magnetic fields. The magnetic compass is affected by vibration and, once disturbed, requires considerable time for stabilization, but vibration does not affect an induction compass and it instantly shows the course on which an aircraft is headed. The induction compass is more easily read than is the magnetic compass, since it is necessary only to keep the pointer of the induction compass indicator on zero to maintain the correct airplane course. By the use of suitable relays, it is possible to use the induction compass to operate mechanical devices. A recording induction compass already has been made and tested by the engineering division of the Air Service in which the energy from the generator was magnified by a relay to operate a pen moving on a rotating drum and an actual record of the course flown was obtained. By further development along this same line, it should be possible to make the induction compass steer an airplane automatically on any desired course.

A Sun Compass.—When navigating in the Arctic or Antarctic regions, where the earth's magnetic poles are located, magnetic compasses are of

little value and neither are those operating on the gyroscopic principle. Astronomical means must be used to secure a method of indicating direction. Owing to the length of the Arctic day light period which lasts six months or thereabouts, the sun is above the horizon for the greater part of the day and since it is nearly always visible, position of the sun can be used as a guide for direction. The Goerz sun compass was constructed for the Amundsen polar expedition. It comprises an optical arrangement of lens and prisms that throws an image of the sun on a screen when the aircraft is on the course set by the navigator. A reflecting prism may be moved around a horizontal axis and set for the declination of the sun. It may also be set according to the time of day and a clockwork device orients the prism automatically. A vertical line is marked on the screen to serve as a "lubber line." When installed, the horizontal part of the optical axis and the longitudinal axis of the airplane are parallel. Deviations from the course are shown by movement of the image on the screen. When the image coincides with the "lubber line," the navigator knows that the plane is following the desired course. If the airplane goes off the course, the sun image on the screen goes either to the right or left of the "lubber line." Reports indicate that this form gave good results in its application by Amundsen and it also was used by Commander Byrd in his epochal North Pole circumnavigational flight.

Radio-Direction Compass.—This navigational aid is of great value to pilots flying between stations equipped with the proper sending apparatus. A series of signals are sent out by ground stations and are received by special apparatus on the plane. The indication when the plane deviates from its course may be received through ear phones or by lights. For example, as long as the plane was on the right path, a certain letter in Morse code would be heard. Going to the left would bring in another letter, going to the right an entirely different signal. If lights are used, as long as a white light is seen, the plane is going in the right direction. A red light indicates deviation in one direction, a green light in the other. When the pilot sees a colored light burning, he steers his plane in a direction necessary to regain his course, which is indicated by the white lamp burning again. This form of compass requires much apparatus, both on the ground and in the airplane and as preparations for a flight along a given course must be made in advance, just as in Air Mail airways, this radio direction indictor has a limited field of application compared to the earth-inductor compass or the magnetic compass. Instead of being a compass, the radio system is more comparable to an airway light or beacon. The principles of operation and the apparatus used have been described fully in publications of the S. A. E. but the subject of radio is out of the scope of a volume of this character, so the foregoing meager description must suffice.

Measurement of Drift.—An airplane or airship covers a course that depends upon various factors. For example, when flying into a side wind, in addition to the forward speed, there is a side drift, varying in intensity with the force and direction of the wind. To fly on a pre-determined course or track relative to the ground, one must be able to approximate the

amount of drift and various forms of instruments have been devised to assist in making such determinations and assisting in navigation. When flying under conditions where good visibility obtains, drift can be estimated by the pilot by comparing his course with landmarks. Some instruments measure drift and ground speed and others have computing mechanism incorporated integrably. In some of these, when the known air velocity has been indicated on the instrument and the drift and ground speed, determined, the velocity triangle has been automatically solved by the integral computing linkage or other mechanism operated by the pilot.

The Pioneer speed and drift meter shown at Fig. 393 is a recently developed instrument that has a unique optical system so the field can be observed from any point occupied by a square foot area about a foot or slightly more from the face of the instrument, without distortion. This permits of mounting the sight on the instrument board, the telescope being

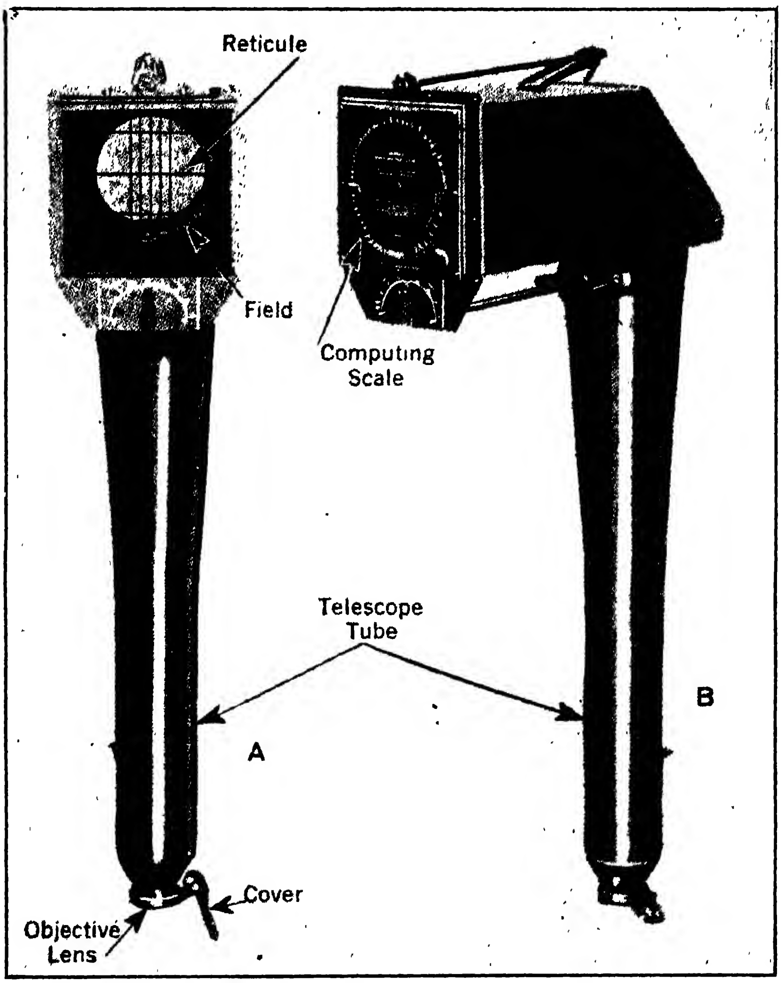

Fig. 393.—Pioneer Speed and Drift Meter. A—Cover Raised to Show Reticule and Field. B—Cover Closed to Show Circular Slide Rule for Computations.

installed back of the board and reaching down through the floor of the cockpit. The cover carries a simple circular slide rule and is mechanically connected with a protective cap on the objective lens so that is always covered when the instrument is not in use and is kept clean.

A reticule, comprising cross wires, some longitudinal for determining drift and some transverse for ground speeds is used in making observations. The reticule unit is turned until the longitudinal wire is parallel to the drift of objects on the ground as seen in the field, by means of a lever pivotted in the lower scale. An index line indicates drift in degrees to the right or left. The time required for the image of any ground object to travel from one transverse wire to the other is found by using a stop watch. When the cover is closed, as at B, Fig. 393, the slide rule is brought into operating position. The inner movable scale carries an index on its upper half and a time scale on its lower half. The outer fixed ring is provided with graduations at the top to read altitude and a lower scale to read ground speeds. The index of the movable scale is set against the proper altitude indication and the ground speed is read in comparison with the time interval. This instrument can be easily operated by the pilot. When the drift angle has been found, the pilot must set his course so the side movement will be compensated for.

Numerous course and distance computers have been devised to aid in navigation, but these and the sextant are specialized instruments that call for experience and technical knowledge in their operation so that they cannot be included in the scope of a general treatise of this character. Sextants are instruments for making observations of the altitude of stars or the sun so independent determinations of position can be used to check results obtained by dead reckoning. Sextants measure the height of the various celestial bodies by indications showing its angular relation to the observer's horizon, which may be either natural or artificial. The latter are necessary whenever a natural horizon is not available.

Airship Instruments.—One of the most important of the instruments used only with airships is known as the manometer and its principal use is in measuring the difference in pressure between the air in the ballonets or the gas in the hull or cells and the external air. The difference in pressures measured by such devices is not large, seldom exceeding 3 or 4 inches head of water. Manometers are of two types, those using a liquid the other operating on mechanical principles. The simplest form is a tube bent in the form of a U partly filled with liquid. If the pressure applied to the top of the liquid in one leg is greater than that of the atmosphere, the liquid will rise in the member open to the air. The reservoir type operates on the same principle as the U tube except that one leg has much more capacity or volume than the other.

When a U tube manometer is used, it will indicate correctly only when level. If one leg is tilted more than the other, the reading will be at fault, because the zero line position is changed. To eliminate this condition, the concentric tube type was devised. This comprises an inner tube carried in an outer concentric bottle of considerably larger diameter so the resulting combination is not only concentric but is a reservoir type as well. If this type is used, there will be but little change of the zero line due to

tilting. The three types are shown at Fig. 394. The simple U tube with legs of equal diameter and volume is shown at A. The amount of rise of the liquid is shown by a suitable scale. In the reservoir type shown B, Fig. 394, owing to the difference in size of the large and small legs a relatively small displacement of liquid in the large leg will cause a much greater vertical displacement in the smaller leg so a device of this type would be more sensitive to pressures of low value than one of the type shown at A. It has the disadvantage of giving wrong readings when tilted, however. The concentic tube type at Fig. 394 C combines with sensitiveness of the reservoir type with the advantage of having but little error when tilted. The scale is marked on the inside tube, which is about 1/4 inch bore, while the outer container is about 13/32 inch bore. The instrument is about seven inches high and the whole is mounted in very thin wall aluminum tubing with a slot cut in it so the scale graduations can be read, the scale being graduated in millimeters with a range of from 0 to 8 centimeters head of water.

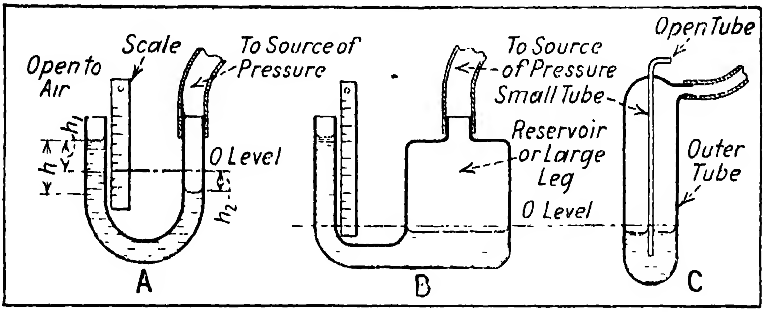

Fig. 394.—Forms of Single Liquid Manometers. A—U Tube Type. B—Reservoir Type. C—Concentric Tube Arrangement.

The mechanical type of Manometer is of the familiar flexible diaphragm form, the pressure element comprising one or more diaphragm capsules or the diaphragm may be of oiled silk with a flat steel spring to oppose its motion. Simple mechanism previously described moves the pointer to correspond to diaphragm movements. The instruments may be obtained with circular or vertical dials. If desired, recording Manometers, may be used to show variations in pressure while in flight at different times to permit of study at leisure. A multiple Manometer of the recording type has been built by the National Advisory Committee for Aeronautics for flight work, this having 30 flat diaphragm capsules arranged around a cylindrical aluminum case. Movements of the diaphragms move small mirrors which throw light reflections on photographic film. The single liquid type Manometer is simple and light in weight and is cheap to manufacture. For general use colored signal oil is used as this has a low vapor pressure, forms a good meniscus and leaves a clean tube when the liquid column changes its position. Kerosene has also been used.

Gas Pressure Alarms.—In rigid airships it is necessary to give warnings when the individual gas cells have become filled due to expansion of gas and excess pressure is beginning to accumulate in them. A pressure alarm

of the push button type has been used. As the gas cell expands or becomes larger in size due to increased pressure the push button is forced against the top of a Sylphon element containing electrical contacts sealed so hydrogen gas leaking from cells cannot be ignited by the spark when the contacts make and break. When the contacts close an electrical circuit a red lamp in the cabin glows to show that there is excess pressure in the cell with which the push button mechanism is in mechanical contact. The button is about 1½ feet in diameter, supported by three springs from the base. Both button and base are of aluminum.

Detectors for Gas Leakage.—Leaks in any cell can be found by portable gas detectors. These usually consist of a chamber provided with a disk of semi-permeable material at one end and a thin metal diaphragm at the other. Since gases used for inflation and air diffuse through the semi-permeable material at differing rates, if the chamber is placed over a leak in a cell, the gas will diffuse into the chamber interior faster than the air will diffuse out and the pressure inside will become greater. The flexible diaphragm will deflect and operate an indicating hand showing amount of leakage.

Measuring Gas Temperature.—Another important consideration in airship operation is the measurement of gas and air temperatures because the lift of any gas is affected by differences in temperature between the lifting gas in the container and that of the surrounding atmosphere in which it floats. It will be evident that the airship operator should know what this temperature difference is at all times. Distance type thermometers of the electrical type are necessary because the points where the gas temperature is measured and the pilot's position may be several hundred feet apart, this distance being too great for the liquid distance type thermometers previously described. There are two types of electrical thermometers. The electric resistance thermometer operates because the resistance of certain conductors varies with temperature. If a fine wire of metal be placed at the point where the measurement is to be made, and a current passed through it, the changes in its resistance can be measured and compared to equivalent temperature variations. The temperature element is usually a coil of nickel wire No. 36 gauge having 200 ohms resistance at 26 degrees centigrade; a sensitive Weston galvanometer indicating changes in current flow through the coil, the electricity being supplied by an 8 volt storage battery. The range of such an instrument built at the Bureau of Standards was from — 30 degrees to + 90 degrees fahrenheit and an accuracy of reading to 1 degree fahrenheit was obtained. The weight, including No. 18 double lamp cord used for leads was less than five pounds.

Another thermometer operates on the principle that currents will be generated at the junction of two dissimilar metals as the temperature changes. A thermo-couple has the advantage that no separate source of electrical energy will be required, as is needed with the resistance type. Unfortunately, the small values of the electromotive force developed by the thermo-couple because of the low temperature difference between the hot and cold ends have made it difficult to apply to aeronautics. Thermo-couple differential thermometers, used to measure temperature differences

between the atmosphere and the gas in the gas bag, known as "superheat meters" have been developed by the Bureau of Standards. This instrument uses couples made of alloys known as Alumel "P" and Chromel "P." Four such couples are placed in series and the voltage developed is read on a Weston galvanometer with a scale graduated to read from — 10 degrees to + 30 degrees fahrenheit superheat. The hot junction is in the gas, the cold junction being covered so no rain can get into its casing, though free circulation of air is provided. As the gas temperature in a cell varies greatly, being much hotter in the upper half than in the lower, the placing of the resistance coil or thermo-couple must be such that an average temperature be measured instead of either of the extremes, especially if the resulting temperature readings are to be employed in computing lift.

Statoscopes.—Instruments used in balloons and airships to detect small variations in pressure and to indicate small variations in height are called statoscopes. They are useful when the pilot is trying to maintain flight at a uniform pressure level. There are two forms of statoscopes, a pneumatic type in which a bubble gives the indication and a mechanical type. The bubble type comprises an air chamber connected to the atmosphere by a curved tube of glass in which a colored oil is placed to seal the air chamber. When the air pressure changes, due to either rise or fall, the liquid moves in the tube and breaks in a trap at one end of the tube, admitting air in the air chamber to equalize that of the external air pressure. Observation of the number of times the bubble breaks provides an approximate idea of the change in altitude. As the bubble will break for a pressure variation of about 20 feet at sea level and 26 feet at 10,000 feet above, it is much more sensitive than an altimeter. As the liquid will move in the curved tube before the bubble reaches the end and breaks, even smaller pressure changes or rise and fall than 20 feet may be determined from the arbitrary scale. A statoscope of the bubble type must be kept in a vertical position to have the bubble breaks occur at uniform pressure differences and also to prevent loss of liquid of which the bubble is composed.

The mechanical type statoscope has an air chamber closed by a flexible, corrugated metal diaphragm, this air chamber being in communication with the air. To secure an indication, the rubber tube is pinched to close it and seal the air chamber. When the tube is closed, if the ship is ascending or descending the pressure difference between the outside air and the inside of the chamber will cause the flexible diaphragm to deflect, this being multiplied by suitable mechanism. The mechanical statoscope is merely a very sensitive altimeter or aneroid barometer that reads zero at any chosen altitude or when the air chamber is open to the air. If the dial is graduated in terms of altitude, the instrument will give correct indications only at one pressure level. The mechanical type is not as sensitive as the bubble type. It has the advantage that the change in altitude may be read directly on the scale if the pressure variation due to the rise and fall of the ship is not too great for the range of the instrument. The pointer is set at zero by a suitable adjustment before taking a reading each time there is a pressure variation because the instrument is operated a level suffi-

ciently greater than the preceding one to be more than the range of indication.

A statoscope with a clock mechanism incorporated that will open and close the air tube valve periodically can be calibrated in units that will indicate rate-of-climb. Sometimes a rubber or oiled silk diaphragm will be used instead of a flexible metal one.

Fire Hazard in Airplanes.—The fire hazard probably is by far the most terrifying of all hazards encountered in aviation. Fires in the air are almost invariably the result of a broken or leaking fuel line, the leakage from which becomes ignited by some leak in the ignition system. The heated exhaust pipes and the products of combustion are not serious

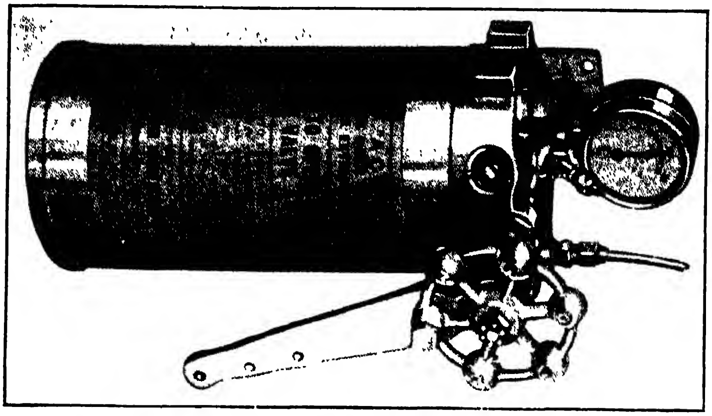

Fig. 395.—Pressure Type Fire Extinguisher Carried in Engine Compartment Contains One Quart of Carbon Tetra Chloride and Sufficient Air to Spray it Around the Engine Compartment when Valve is Opened.

sources of ignition in flight due to the high velocity of airflow around the exhaust area. Fires therefore occur in the engine compartment or in the first cowled-in bay of the fuselage. All airplanes have a metal or metal and asbestos fire-wall built into the fuselage in the wake of the engine and carry a pressure fire-extinguisher. This is illustrated in Fig. 395. The fire-extinguisher has a capacity of about 1 quart of carbon tetrachloride and sufficient compressed air to spray it around the engine compartment.

In its latest form, the fire-extinguisher is built in the form of a cylinder with a central tube. The tube contains air compressed to approximately 100 pounds per square inch. The outer space contains the tetrachloride fluid. Two needle valves mounted in the head are connected to a yoke which is operated by a quick acting thread. The valve actuating lever is arranged for manual control by the pilot. When the valves are opened, compressed air is admitted to the liquid container and the liquid outlet is opened to discharge the fluid over and around the engine. The extinguisher is mounted as close to the engine as possible to reduce the piping required. The results of a large number of crash tests at McCook Field indicate that hot exhaust pipes are the most common source of ignition of both leaky gasoline and engine oil escaping from a ruptured oil system or

broken crankcase. This condition has been reduced by the use of short stacks in service machines. It would seem that covering the exhaust pipes with asbestos cord and further protecting this with an outer layer of metal would greatly reduce the risk from fire due to hot exhaust pipes.

Some Notes on Aerial Navigation.—Bradley Jones of the Engineering Division, Air Service, McCook Field read an interesting paper before the Dayton Section of the S. A. E. on Aerial Navigation from which the following excerpts have been taken. Aerial navigation is the art of utilizing all possible aids to enable an aircraft to accomplish its mission efficiently under adverse, as well as favorable, conditions. This implies not merely flying the most direct course but selecting the altitude that has the best meteorological conditions, such as visibility, favorable winds and other important factors.

Navigation, whether aerial or nautical, presents the two problems of (*a*) ascertaining one's geographical position and (*b*) maintaining a direction. If the direction of movement is known, the first problem is greatly simplified. The proces of navigating a ship at sea is roughly as follows: Position of the ship is ascertained by observations of the sun or stars. Allowance is made for estimated ocean currents and expected drift due to wind, and a course is set that should bring the ship to its destination. A log registers the number of miles the ship travels ahead through the water. A position can be deduced at any time by reading the log and assuming that the registered distance has been travelled along the set course except for drift and current. This deduced reckoning or, as it is usually termed, "dead-reckoning," is liable to considerable error. Whenever a position is found by astronomical observation, it is assumed to be correct and the discrepancy between the dead-reckoned position and that found by sextant observation is usually attributed to "current." This "current" includes not only the difference in position due to flow of the water but also the errors due to imperfect steering, improper allowance for compass error and drift and inaccurate logging.

In the air, navigation by dead-reckoning is extremely difficult when out of sight of land, because of the variability of air currents, or winds. At sea, the movements of the water are well known and have been charted. Ocean currents are due principally to trade winds and are practically constant. The movement of the swiftest current, the Gulf Stream that flows between Florida and the Bahamas, is only 5 m.p.h. Air currents vary from hour to hour and differ at different altitudes. Winds of 40 to 50 m.p.h. are not uncommon, and much higher velocities may be encountered.

Much misconception has arisen through the use of the term "drift" to designate the extent to which an airplane is carried off its course by wind. At sea, drift or "leeway" refers to the distance a ship is blown sideways through the water by the force of the wind on the hull and superstructure above the water. An airplane, which is wholly in the air and moves forward under the action of its engine and propeller, never moves sideways through the air; if the air moves, the airplane is carried with it and describes a path with respect to the ground that differs from the direction of its heading.

Drift can be measured from an airplane on most cross-country flights by any of several sighting devices. If the angle of drift is known, the course of the airplane is altered to result in "crabbing" into the wind so that a correct course over the ground is flown. Even on cloudy days there are usually rifts or holes in the clouds through which sufficient glimpses of the ground can be obtained for measuring the drift. Weather conditions change much more quickly in a north-and-south direction than in an east-and-west direction; therefore, when flying north or south it is wise to obtain drift measurements about every 50 miles, whereas, when flying east or west, a measurement every 75 or 100 miles is usually often enough.

Drift measurements from the airplane are impossible when clouds entirely obscure the ground. Various plans that involve the use of a longitudinal wire which cuts the earth's lines of force or of a ball rolling on a flat plate have been proposed for taking such measurements, but none of these schemes has been made practical as yet.

Major Blair, of the Signal Corps, has devised a method of measuring wind velocities above clouds from a station, and if the wind velocity is radioed to aviators in the air the information can be used to correct their courses. Without this definite information, only approximations can be made. The turning of winds with altitude is known in a general way, and by studying weather maps a rough idea can be obtained of the probable winds that will be encountered.

An aviator, when flying over land, needs a good compass to enable him to fly a straight course, and he must be kept informed of his drift so that this straight course shall be the correct path to his destination. Without both a reliable compass and drift knowledge, the aviator must follow railroads, highways and rivers and consequently must fly a devious course. A knowledge of direction and drift are also necessary when flying over water. Since objects on which to sight are absent, the airplane carries smoke bombs or flares, which are dropped whenever a drift measurement is desired.

Sextant observations are made in much the same way as from ships, and if the airplane is low enough for the sea horizon to be used, the same degree of accuracy is obtainable. An artificial horizon is used when clouds or haze hide the true horizon, but the accuracy of these "shots" is much less than that obtained with the true horizon, although it probably is of a higher order than is the accuracy of dead-reckoning.

The polar flights in the spring of 1926 presented some peculiar problems in navigation. Everyone probably realizes that if one starts from any point on the earth and flies due north, he will reach the North Pole, barring mishaps. It is not so commonly appreciated that, starting from any point and flying any northerly course between 89 and 271 degrees by compass, the North Pole will be reached eventually by way of a spiral course. Starting from the equator and flying due north, the pole is reached after travelling 6,300 miles; but if one starts at the equator and flies continuously an 89 degree course, he will travel more than 350,000 miles to reach the pole.

Navigating the N.C. Boats.—Novel instruments that were especially invented or designed for use in oversea navigation were employed in prac-

tice for the first time by the Navy-Curtiss seaplanes in the famous transatlantic flight made a number of years ago. No airplane had ever flown far enough out to sea to warrant the use of the sun, moon and stars for fixing a geographical position as is done on seagoing ships prior to this flight. Navigation, therefore, on a transatlantic flight was new and untried and it was necessary in preparing for this flight to design three new instruments for navigational use. These were an aerial sextant, a drift and speed indicator and a course and distance indicator. Since the time of Columbus celestial bodies have been used to locate the position at sea, but to do this a clear day has been necessary so that the observer could take the altitude of the heavenly bodies.

For this flight, however, an instrument was designed that will enable the air navigator to locate his position regardless of the state of weather and regardless of the very fast speed of airplanes. A unique feature of the Byrd aerial sextant designed by the man who was to be the first to pilot an airplane to the North Pole and back some years later is that a bubble in a tube takes the place of the sea horizon in the observations. A specially constructed lens is used in sighting the bubble, which is reflected in a mirror. The sun is reflected in another mirror. The observer brings the sun tangent to a line at the same time he brings the bubble tangent to the line. That gives the altitude of the sun. This is of especial value as the aviator is often above the clouds and even when flying at low altitudes the horizon is too dim to be seen clearly. With this new aerial sextant the curvature of the earth does not have to be taken into consideration in calculating position. The bubble is lighted at night, so that night observations may be taken. New methods of astronomical calculations were also devised which enabled the navigator to make his calculations in a fifth of the time that was formerly necessary. A zenithal projection chart of the Atlantic Ocean was specially constructed for this purpose. This chart, a new invention, did away with difficult mathematical calculations enabling the aviator to determine his position in a few minutes.

Another great problem of the sea-air navigator is the calculation of the speed and direction of the wind, both day and night. In spite of the reliability of the compass, it can only give the course upon which the craft heads, and in determining the true course, proper allowance must be made for the sidewise drift caused by the wind. For example, a wind blowing 30 miles per hour toward the side of the plane will blow it 30 miles per hour out of its course. This fact alone makes the navigation of the air far more difficult than the navigation of the sea. To overcome this difficulty bombs have been invented which ignite upon striking the surface of the water and give a dense smoke and bright light for 10 minutes. An instrument used in conjunction with this bomb enables the navigator to determine the velocity and direction of the wind by sighting on the smoke in the daytime and the light at night. This instrument, called the speed and drift indicator, has proved successful. When the navigator has found the speed and direction of the wind, he must then be able to calculate the course to steer to allow for this wind. To do this an instrument has been designed to solve the triangle of forces, thus doing away with cumbersome mathematical calculations.

The navigator's cockpit of the N.C. boat seaplane was in the fore part of the hull and was equipped with a chart board, a chart rack and lamps. He also had a specially designed headgear for telephone communication with the pilots so that he can direct them when to change the course. The noise from the four big engines was so great that it was impossible to hold conversation except with specially designed telephone apparatus. The navigator also had instruments to show him the altitude of the plane and the time the sun keeps with the Greenwich meridian, because in going to the eastward so rapidly it is difficult to keep the correct time. In going from Newfoundland to the Azores, over 2 hours was lost in a period of 20 hours, so that the navigator must be very expert to allow for this loss in time in making his astronomical calculations. In aerial navigation positions must be determined very quickly. The navigator sits down to work out his "sights" to fix his position and will be far from his calculated position unless he works out his calculations very rapidly, which these instruments enable him to do.

Night Flying.—Pilot Wesley L. Smith, of the Air Mail Service, who has been flying between New Brunswick, N. J. and Cleveland, Ohio, read a very interesting paper before the S. A. E. at the annual aeronautical meeting held in 1926 in which he outlined some very interesting facts. A portion of the route, that between Bellefonte, Pennsylvania and Cleveland, Ohio, is shown at Fig. 396. A profile map is shown so that the heights of the various hills and mountains between the two points can be ascertained. Beacons are placed on mountain tops and on emergency landing fields. Beacons on mountains revolve in one direction, on emergency fields in the opposite direction. The mountain top beacons are surmounted by red lights as an additional distinction. Each terminal field and emergency field is bounded by lights about 250 feet apart and all obstacles are surmounted by red lights. The best approaches to the field are indicated by green boundary markers. Flood lights are used for terminal field illumination but when landing on emergency fields, the pilot has recourse to a parachute flare and large landing lights on the machine. The distance between beacons is about 8 miles and landing fields about 17 miles. In addition to beacons, the pilot can see the lights of cities and towns along the route and also locates himself by large factories, blast furnaces and amusement parks. Lighted railroad trains are often used as guides when their direction of travel can be determined. Headlights of automobiles indicate main highways. Railroad roundhouses at division points are aids and even mountains and bodies of water in the vicinity of lighted areas are of value. An almost unbroken stretch of well lighted factory cities extends from Pittsburgh to Cleveland that have been used by Pilot Smith to guide him on his course. The emergency landing fields are close together on this route because the nature of the terrain is such that safe landings, other than on those fields would be difficult at night and the pilots would depend on their parachutes in an emergency that would call for a landing between fields.

Plane and Equipment for Night Flying.—In order to do this sort of flying, much depends on the airplane, and very definite requirements must be met by it. First in order are the flying qualities, the most important of

of which is stability. In order to do much flying by instruments, we must have an airplane that is stable fore-and-aft, laterally and directionally. It must fly "hands off" whether flying level, climbing or descending in fairly rough weather. Flying by instruments is an intense physical and mental strain and the pilot needs as much relief as he can get from a stable plane. The plane must be extremely maneuverable for getting into and out of poor emergency fields that are surrounded by obstacles. It must have a slow landing-speed, because these fields are mostly small. It must have a rapid climb, to clear obstacles on a take-off and to climb quickly above clouds whose moisture may freeze on the ship and soon weigh it down to the ground. It must have a cruising-range that will carry us, non-stop, from New York City to Cleveland against a 30-mile headwind, because the intervening country may be covered with storms that make safe landing impossible. In addition to this, fuel for an extra hour is needed to enable us to locate the course, if it has been lost on the way in bad weather.

The special night flying plane equipment consists of the following: three navigation lights, one on each wing-tip and one on the tail, to enable pilots to see other ships en route; two large headlights for landing in emergency fields that are not equipped with flood lights, these are somewhat similar to automobile headlights but are much more powerful; and two large magnesium parachute flares, one of which will light 1 square mile of area brilliantly from an altitude of 2,000 feet and thus will disclose and emergency field and all its obstacles. It burns long enough to allow plenty of time for landing. These flares are fairly reliable but occasionally fail to light, so two are carried by each plane. They are more generally used than the landing lights because of the many obstacles about the emergency fields.

Our five senses are not keen enough to enable us to fly straight.when nothing is visibile outside the ship, so we must have some instruments to aid us. All the navigation instruments are grouped closely in the center of the instrument board, so that they all can be seen at once. A very important navigational aid is the compass. Inasmuch as the magnetic north pole is in the neighborhood of 70 degrees north latitude and 97 degrees west longitude or to the northwest of Hudson Bay, the meridian on which an uncompensated compass would be correct passes over the Atlantic Ocean off our coast. Compasses must be compensated to make them show the correct direction, and they can only be compensated in one locality. A compass compensated correctly at Cleveland is 11 degrees off at New York City. No roads or cities near New York City are laid out on north and south lines, whereas, in Ohio, they nearly all are so laid out. Compasses consequently, are adjusted in Cleveland and the variations along the way to New York City must be known. The compasses must also be compensated to overcome the effects of the metal parts of the plane. As our course is not straight, allowance for that must also be made.

The earth's magnetic field is parallel to the earth's surface only at the equator. In our latitude, it dips about 60 degrees and the compasses must be balanced accordingly. This makes every compass a pendulum and proper allowance must be made. Raising the nose of the ship suddenly causes the compass to swing to the north; lowering the nose suddenly

causes it to swing to the south. In turning toward the north, the compass generally reads correctly, but turning toward the south causes it to swing past or farther than it should and to oscillate before coming to rest. So, sudden maneuvers must be avoided in navigation flying. During storms, when a compass is most needed, the plane is tossed about and does all the things just mentioned in spite of the pilot's best endeavors. Under the compass, therefore, is a turn indicator.

The turn indicator records reactions on a spinning gyroscope, the pointer indicating the direction in which the ship is turning. In rough weather, the pilot tries to keep the pointer straight down and to hold to the average reading of the compass, the proper one for the course. The compass generally swings somewhat in a storm. The turn indicator will show

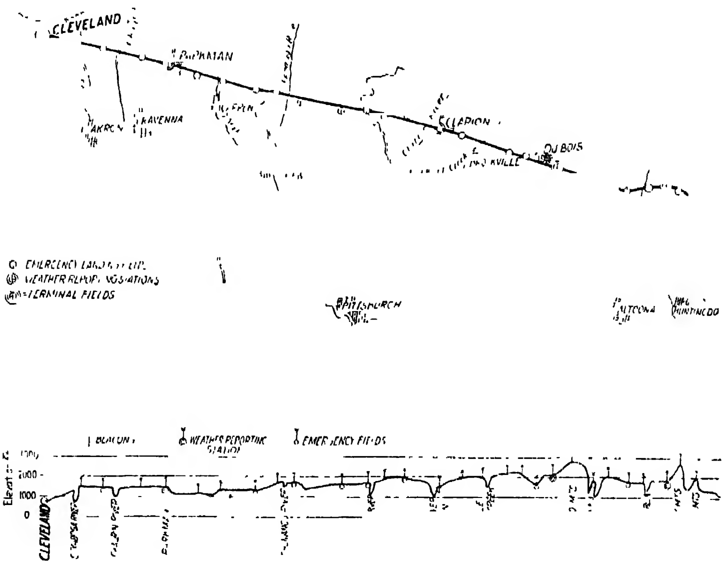

Fig. 396.—Map Showing Territory from Bellefonte, Pa., to Cleveland, Ohio, on the New York to Cleveland Air Mail Route. Note Profile Showing Elevations, also Location of Beacons and Emergency Landing Fields.

the turn for a second to one side, if a bump drops that wing, so quick movements must be disregarded in rough storms.

Under the turn indicator is the bank indicator, which consists of a steel ball in a slightly larger curved glass tube filled with alcohol, to dampen the vibrations. The steel ball remains in the center during level flight or while making a perfect turn that is properly banked. Any deviation from the center shows a low wing. If a turn is being made and the ball follows the pointer, the plane is overbanked and a side-slip results; if the ball goes in the opposite direction, the plane is underbanked and a skid results.

An altimeter, is placed at the left of the bank indicator. This consists of a sensitive diaphragm on one end of an enclosed cylinder. This dia-

phragm moves in and about as the air pressure on the outside varies, its action being multiplied to move the hand on the dial. On the dial are two scales. The outer full one is calibrated in feet so that the hand will record changes of altitude to correspond to changes of air pressure. But the air pressure at any spot changes constantly due to the approach of storms, which are low pressure areas, or to clear weather, which is a high pressure area; consequently, these changes may cause the pointer to show a change of altitude of 1,000 feet while the airplane is remaining quietly in the hangar. The altitude scale, therefore, is movable and, before a trip is begun, is set so that the hand will point to the elevation of the starting point above sea level. Each of the fields is at a different elevation and, to take this into account, all elevations are referred to sea level.

This instrument, since it measures changes of air pressure, is also a barometer. The small inside scale is calibrated to read pressures corresponding to inches of mercury on a regular barometric scale and is set by comparing it with that of a standard barometer. The scale shows only the range from 29 to 31 inches, which is the common variation of a barometer at sea level. The barometric pressure may, and usually does, vary over a route, so that the altimeter, although set correctly at New York City, will show a wrong elevation upon landing at some other field where the barometric pressure is different. There are barometers at New York City, Bellefonte and Cleveland, and the reading at the next station is obtained before beginning a trip. For sake of simplicity, these barometers are all corrected to give the reading as it would be at sea level. The movable altitude scale is then turned until its zero is opposite the barometer reading of the field toward which the airplane is travelling; when that field is reached, the altimeter will show the correct elevation upon landing. The altimeter, being correct for that area, then tells me how high to fly to clear all mountain peaks nearby.

An air speed indicator is operated by a pitot tube on a wing strut outside the propeller wash. The air pressure varies with the speed at which the airplane is travelling through the air, so the instrument is calibrated to read in miles per hour. Knowing the cruising speed of the airplane, any climb or descent is indicated first by this instrument and then by a change of the altimeter. By its use, the airplane may be kept within safe climbing and descending speeds and may also be kept level fore and aft. This instrument is also useful in detecting the formation of ice. If the tachometer shows no variation but the air speed apparently drops, ice is forming in the throat of the pitot tube and will shortly put it out of commission.

The tachometer, indicating the speed at which the engine turns, may also be used to check climbs or descents. With a fixed throttle, the engine slows down in climbing and speeds up in descending.

Influence of Weather.—Pilot Smith states that inclement weather is one of the greatest troubles experienced by pilots flying at night. Fog is the worst enemy of pilots of airplanes, just as it makes marine navigation so difficult. If the fog is thin, that is not more than 1,000 feet thick, beacons and city lights will show through it, at least enough to keep a pilot on his course. If a bright moon is shining on the fog, nothing can be seen through it. It is often possible to fly around rain storms and these are not par-

ticularly dangerous even if the pilot must fly through them. Fogs and rains are spring and summer conditions.

Autumn brings longer and more severe rainstorms and thicker fogs than summer, but they are not so frequent. Many times fog forms as the sun evaporates the frost at sunrise. Winter brings snow. In snowstorms, the clouds are usually higher, touching only the topmost mountain peaks, but the visibility is poor. Usually straight down is all that one can see. A severe blizzard over a landing field would, of course, make landing there impossible. Snow on the ground is a great help in flying. Even on the darkest night, it is possible to see the ground, mountains and the like, when they are snow-covered. But, on the other hand, deep snow on landing fields prevents their use. It is not often that there is enough snow on the ground all the way from New York City to Cleveland to use skis. So, the main fields are rolled to pack the snow and pilots can land and take-off with the wheels. But, in the meantime, emergency fields are worse than useless, for the unlucky man who lands there must await a thaw or the coming of skis from a terminal field. Snow squalls of short duration are more frequent in winter than are thunder storms in summer, but they are not bad for us.

The greatest of all our problems is ice. When the temperature ranges from the freezing point down to about 10 degrees above zero fahrenheit, moisture in the clouds will freeze on the airplane, first upon the wires, then upon the struts and the fabric, loading the airplane and creasing its resistance until it is forced down. When this happens the landing-speed is usually 20 or 30 m.p.h. higher than normal, due to the increased load. When the temperature is below plus 10 degrees fahrenheit, the clouds are apparently composed of minute ice crystals that cannot and do not freeze on the ship.

If the clouds touch only the highest points, it is possible to fly just below them except at the high points, and the few minutes required to pass these points does not put on much ice. The other alternative is to fly above the clouds, climbing through them rapidly to avoid an excessive load of ice. This is usual eastbound, but can seldom be done westbound because of the prevailing west wind and the loss of speed by the airplane when aloft. As a result eastbound trips, under those conditions, are more likely to be completed than are westbound trips. The ice coats the wires to three times their usual size. It coats the propeller unevenly, thus unbalancing it, and the resulting vibration sometimes snaps wires on the wings before the ship becomes overloaded.

It is sometimes warmer above the clouds than in them. Pilot Smith stated that he has several times lost the ice above the clouds that he had gathered while climbing through them. The temperature usually drops 1 degree for each 300 feet of climb, so it is sometimes possible to stay below the freezing zone when the lower strata are warmer. This is more common in the spring and autumn when ground temperatures range around 40 degrees and we can just clear our high points below the freezing zone in the clouds.

When forced to land on an emergency field, on account of bad weather at the next terminal field, we do not stop the engines, in winter. It is too

hard to drain and refill them with water and oil and to get started again. An engine may be idled several hours, using very little fuel and oil, and the flight resumed when the weather breaks. Engines are very hard to start when cold and the caretaker of an emergency field is not of enough assistance. When an engine must be stopped in winter, it is usually necessary to send two mechanics to the pilot's assistance to get it started again.

Spring brings snow squalls, much sleet that freezes on the planes causing many forced landings and much fog. Fog is caused by alternate thawing and freezing, each thaw generally producing a fog. This alternate thawing and freezing makes all the fields soft and much care must be exercised in landing, even on the terminal fields.

QUESTIONS FOR REVIEW

1. Name different classes of airplane instruments.
2. What are the important power plant instruments?
3. What instruments are especially valuable in helping the pilot control his plane?
4. What instruments are essential to aerial navigation?
5. Name instruments used only in airships.
6. What is the difference between a centrifugal and chronometric tachometer and for what purpose are these used?
7. What is the principle of operation of a distance type thermometer, of an air speed indicator?
8. What is an earth induction compass and why is it valuable in aircraft?
9. What is a manometer, a statoscope, a gas pressure alarm?
10. What is the difference between an aneroid altimeter and a barograph?

CHAPTER XIX

STANDARD NOMENCLATURE FOR AERONAUTICS
REPORT No. 240—PART I
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Definitions of all Important Terms Used in Connection With Aviation and Aerostation Arranged in Alphabetical Order for Ready Reference.

absolute inclinometer—See INCLINOMETER, ABSOLUTE.

accelerometer—An instrument for indicating, measuring, or recording accelerations.

aerodynamic volume—See VOLUME, AERODYNAMIC (AIRSHIP).

aerodynamics—The branch of dynamics which treats of the motion of air and other gaseous fluids and of the forces acting on solids in motion relative to such fluids.

aeronautics—The science and art pertaining to the flight of aircraft.

aerostat—A generic term for aircraft whose support is chiefly due to buoyancy derived from aerostatic forces. The immersed body consists of one or more bags, cells, or other containers, filled with a gas which is lighter than air.

Syn.—LIGHTER-THAN-AIR CRAFT. Includes airship and balloon, q. v.

aerostatics—The science that treats of the equilibrium of gaseous fluids and of solid bodies immersed in them.

As an aeronautic term, it relates to those properties of lighter-than-air craft which are due to the buoyancy of the air.

aerostation—The art of operating aerostats.

aileron—A hinged or pivoted movable auxiliary surface of an airplane, usually part of the trailing edge of a wing, the primary function of which is to impress a rolling moment on the airplane. (Fig. 397.)

aileron angle—See ANGLE, AILERON.

air controls—See CONTROLS.

aircraft—Any weight-carrying device or structure designed to be supported by the air, either by buoyancy or by dynamic action.

air duct—A tube, usually of fabric, supplying air for filling or for maintaining pressure in air filled parts of an aerostat.

(*a*) The duct joining the vertical and lateral lobes of a kite balloon. Sometimes called "interconnecting sleeve" or "trousers" (British).

(*b*) The duct leading from the air scoop or blower of a non-rigid or semi-rigid airship to the ballonet or ballonets.

airfoil—Any surface designed to be projected through the air in order to produce a useful dynamic reaction.

airfoil section (or profile)—A cross section of an airfoil made by a plane parallel to a specified reference plane. A line perpendicular to this plane is called the axis of the airfoil.

air log—An instrument for measuring the linear travel of an aircraft relative to the air. One form consists of a windmill with a revolution counter.

airplane—A mechanically driven aircraft, heavier than air, fitted with fixed wings, and supported by the dynamic action of the air.

airplane, pusher—An airplane with the propeller or propellers in the rear of the main supporting surfaces.

airplane, tandem—An airplane with two or more sets of wings of substantially the same area (not including the tail unit) placed one in front of the other and on about the same level.

airplane, tractor—An airplane with the propeller or propellers forward of the main supporting surfaces.

airport—A locality, either of water or land, which is adapted for the landing and taking off of aircraft and which provides facilities for shelter, supply, and repair of aircraft; or a place used regularly for receiving or discharging passengers or cargo by air.

air scoop—A projecting scoop which uses the wind or slip stream to maintain air pressure in the interior of the ballonet of an aerostat.

A similar device is sometimes used on airplanes to produce ventilation.

airship—An aerostat provided with a propelling system and with means of controlling the direction of motion. When its power plant is not operating, it acts like a free balloon.

non-rigid—An airship whose form is maintained by the internal pressure in the gas bags and ballonets.

rigid—An airship whose form is maintained by a rigid structure.

semi-rigid—An airship whose form is maintained by means of a rigid or jointed keel in conjunction with internal pressure in the gas containers and ballonets.

The term "airship" is sometimes incorrectly applied to heavier-than-air craft either in full or as "ship." This is a slang use of the word and should be avoided.

airship dope—See DOPE, AIRSHIP.

airship station—See STATION, AIRSHIP.

air speed—The speed of an aircraft relative to the air. Its symbol is V.

air-speed meter:

air-speed indicator—An instrument for indicating the speed of an aircraft relative to the air. It is actuated by the pressure developed in a suitable pressure nozzle or against a suitable obstruction and is graduated to give true air speed at a standard air density.

The speed indicated by the instrument is termed the "indicated air speed." (The indicated speed is a direct measure of the lift or drag exerted on the airplane at any altitude. Stalling at all altitudes occurs for the same value of the indicated speed.)

true air-speed meter—An instrument for measuring the true speed of an aircraft relative to the air. The Biram and Robinson anemometers are of this type.

air volume (airship)—See VOLUME, AIR (AIRSHIP).

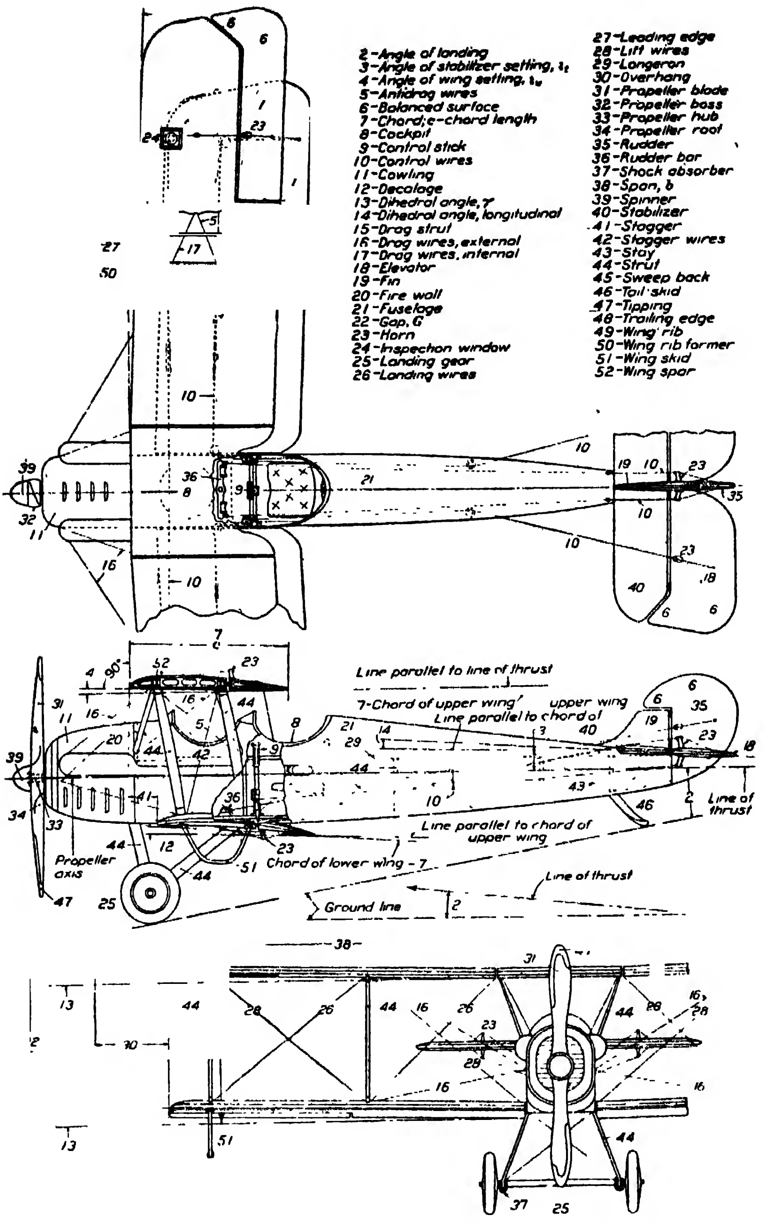

Fig. 397.—Plan and Side and Front Elevations of Biplane Showing Parts and Recommended Nomenclature.

air-volume displacement—See DISPLACEMENT, AIR VOLUME.

airway—An air route between air traffic centers which is over terrain best suited for emergency landings, with landing fields at intervals equipped with aids to air navigation and a communication system for the transmission of information pertinent to the operation of aircraft.

The term "airway" may apply to an air route for either landplanes or seaplanes or both.

alarm, gas-cell—A device, fitted adjacent to a gas cell, which indicates or warns when a pre-determined limiting pressure has been reached in the gas cell. Also called "pressure alarm."

altigraph—An altimeter equipped with a recording mechanism. Present instruments are of the aneroid type. The chart, driven by clockwork, is usually graduated in feet or meters in accordance with some empirical or arbitrary pressure-temperature-altitude formula. In other words, it is a barograph whose scale is designed to read heights.

altimeter—An instrument for measuring or indicating the elevation of an aircraft above a given datum plane.

altimeter, aneroid—An altimeter, the indications of which depend on the deflection of a pressure-sensitive element. The graduations of the dial correspond to an empirical or arbitrary pressure-temperature-altitude formula.

altimeter, electrical-capacity—An altimeter, the indications of which depend on the variation of an electrical capacity with distance from the earth's surface.

altimeter, engine—An altimeter for indicating the altitude corresponding to the pressure produced in the intake manifold of a supercharged engine.

altimeter, optical—An altimeter, the indications of which depend on the manipulation of a suitable optical system.

altimeter, sound-ranging—An altimeter, the indications of which depend on the measurement of the time required for a sound wave to travel from the aircraft to the earth and back.

amphibian—An airplane designed to rise from and alight on either land or water.

anchor, sea—An open fabric bag carried on an aircraft and arranged to offer considerable resistance when towed mouth first through the water. Tripping or collapsing devices may be incorporated in it. Also called "drogue."

anchorage, snatch-block—An anchorage set in the ground for a snatch block used with a yaw line from a mooring mast. The anchorage may be of concrete or timber and are usually arranged at equal intervals around the circumference of a circle whose center is the mast; may also be applied to any anchorage for a snatch block used in hauling down an airship or kite balloon.

anemometer—An instrument for indicating or measuring the speed of an air stream.

aneroid altimeter—See ALTIMETER, ANEROID.

angle, aileron—The angular displacement of an aileron from its neutral position. It is positive when the trailing edge of the aileron is below the neutral position.

angle, critical—An angle of attack at which the flow about an airfoil changes abruptly with corresponding abrupt changes in the lift and drag.

angle, downwash—The angle through which an air stream is deflected by any lifting surface of an airplane. It is measured in a plane parallel to the plane of symmetry and is denoted by the symbol e.

angle, drift—The horizontal angle between the longitudinal axis of an aircraft and its path relative to the ground.

angle, effective helix—The angle of the helix described by a particular point on a propeller blade as the airplane moves forward through air otherwise undisturbed. It is equal to the angle whose tangent is the ratio of the velocity of flight to the product of the four quantities: 2 π, r (the distance from the axis to the point in question) and n (the number of revolutions per second), i.e.,

$$\Phi = \tan^{-1}\left(\frac{V}{2\pi rn}\right)$$

angle, elevator—The angular displacement of the elevator from its neutral position. It is positive when the trailing edge of the elevator is below the neutral position.

angle, landing—The acute angle between the line of thrust of an airplane and the horizontal when the airplane is resting on level ground in its natural position. Also called "ground angle."

angle, longitudinal dihedral—The difference in angle of wing setting and of stabilizer setting. (This angle is positive when the angle of stabilizer setting, referred to the thrust line, is less than the angle of wing setting.)

angle, minimum gliding—The acute angle between the horizontal and the most nearly horizontal path along which an airplane can descend steadily in still air when the propeller is giving no thrust.

angle of attack—The acute angle between the chord of an airfoil and its direction of motion relative to the air. (This definition may be extended to other bodies than airfoils.) Its symbol is a.

angle of incidence of wing—See ANGLE OF WING SETTING.

angle of pitch—The acute angle between two planes defined as follows: One plane includes the lateral axis of the aircraft and the direction of the relative wind; the other plane includes the lateral axis and the longitudinal axis. (In normal flight the angle of pitch is, then, the angle between the longitudinal axis and the direction of the relative wind.) This angle is denoted by Θ and is positive when the nose of the aircraft has risen.

angle of roll, or angle of bank—The acute angle through which an aircraft must be rotated about its longitudinal axis in order to bring its lateral axis into a horizontal plane. This angle is denoted by Φ and is positive when the left wing is higher than the right.

angle of stabilizer setting—The acute angle between the line of thrust of an airplane and the chord of the stabilizer.

angle of wing setting—The acute angle between the plane of wing chord and the line of thrust. It may differ for each wing.

angle of yaw—The acute angle between the direction of the relative wind and the plane of symmetry of an aircraft. This angle is denoted by Ψ and is positive when the aircraft has turned to the right.

angle, propeller-blade—The acute angle between the chord of a propeller section and a plane perpendicular to the axis of rotation of the propeller. Usually called "blade angle."

angle, rudder—The acute angle between the rudder and the plane of symmetry of the aircraft. It is positive when the trailing edge has moved to the left with reference to the normal position of the pilot.

angle, wing-dihedral or dihedral—The acute angle between the transverse reference line in the wing surface and the lateral axis of the airplane projected on a plane perpendicular to the longitudinal axis. The dihedral angle is positive when the upper obtuse angle for the two wings is less than 180 degrees.

angle, zero-lift—The angle of attack of an airfoil when its lift is zero.

anti-flutter wire—See WIRE (AIRSHIP), ANTI-FLUTTER.

apparatus, water-recovery—Apparatus carried on an airship for condensing and recovering the water contained in the exhaust gases of internal combustion engines in order to avoid the necessity of valving gas as the fuel is consumed.

appendix—The tube, usually located at the bottom of a balloon, primarily used for inflation and deflation. In the case of a free balloon it may also serve as an automatic-discharge opening.

Originally applied to free balloons only. Should be restricted to the various types of balloons and not applied to airships.

appendix manhole—See MANHOLE, APPENDIX.

apron—A hard surface area of considerable extent immediately in front of the entrance to a hangar or aircraft shelter which is used for the handling of aircraft or for repair in clear weather.

aspect ratio—The ratio of span to mean chord of an airfoil; i.e., the ratio of the square of the maximum span to the total area of an airfoil.

aspect ratio of propeller blade—Half the ratio of propeller diameter to maximum blade width.

attitude—The position of an aircraft as determined by the inclination of its axes to some frame of reference. If not otherwise specified, this frame of reference is fixed to the earth.

automatic valve—See VALVE, AUTOMATIC.

aviation—The art of operating heavier-than-air craft.

axes of an aircraft—Three fixed lines of reference, usually centroidal and mutually perpendicular. The longitudinal axis in the plane of symmetry, usually parallel to the axis of the propeller, is called the longitudinal axis; the axis perpendicular to this in the plane of symmetry is called the normal axis; and the third axis perpendicular to the other two is called the lateral axis. In mathematical discussions, the first of these axes, drawn from front to rear, is called the X axis; the second, drawn upward, the Z axis; and the third, running from right to left. the Y axis.

axial cable—See CABLE, AXIAL.

axial cone—See CONE, AXIAL.

B

bag, gas—See HULL (AIRSHIP), and CELL, GAS, which are to be preferred, according to the type and use.

balanced surface—A control surface which extends on both sides of the axis of the hinge or pivot in such a manner as to reduce the moment of the air forces about the hinge.

ballast—Any substance, usually sand or water, carried in a balloon or airship and intended to be thrown out, if necessary, for the purpose of reducing the load carried and thus altering the aerostatic relations.

ballonet—A compartment of variable volume constructed of fabric, or partitioned off, within the interior of a balloon or airship. It is usually partially inflated with air, under the control of valves, from a blower or from an air scoop. By the blowing in or letting out of air, it serves to compensate for changes of volume in the gas contained in the envelope and to maintain the gas pressure, thus preventing deformation or structural failure. By means of two or more ballonets, often used in non-rigid airships, the trim can also be controlled. The ballonet should not be confused with gas cell.

ballonet diaphragm—See DIAPHRAGM, BALLONET.

ballonet-fullness indicator—See INDICATOR, BALLONET-FULLNESS.

balloon—An aerostat without a propelling system.

barrage—A small captive balloon, used to support wires or nets which are intended as a protection against attacks by aircraft.

captive—A balloon restrained from free flight by means of a cable attaching it to the earth.

constant pressure*—A supply balloon arranged to maintain a constant pressure of gas in a moored or docked aerostat.

free—A balloon, usually spherical, whose ascent and descent may be controlled by use of ballast or with a loss of the contained gas, and whose direction of flight is determined by the wind.

kite—An elongated form of captive balloon, fitted with lobes to keep it headed into the wind and usually deriving increased lift due to its axis being inclined to the wind.

nurse*—Sometimes used to refer to a constant-pressure balloon.

observation—A captive balloon used to provide an elevated observation post.

pilot*—A small balloon sent up to show the direction and speed of the wind.

propaganda—A small free balloon sent up without passengers but with a device by which papers or documents may be dropped at intervals.

sounding*—A small balloon sent up without passengers but with recording meteorological instruments.

supply*—A container made of heavy fabric employed as a portable means of storing gas at low pressure. It is usually too heavy rise, even if free.

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* Those forms of balloons marked with an asterisk (*) are not, strictly speaking, aircraft.

triangulation*—A small captive balloon used as a mark on which to sight in a triangulation survey.

balloon bed—A mooring place on the ground for a captive balloon.

balloon fabric—See FABRIC, BALLOON.

band:

drip—See FLAP, DRIP.

mooring—A band of tape or webbing, over the top of a kite balloon, to which the mooring ropes are attached. It forms part of a mooring harness.

suspension—A horizontal fabric band, securely fastened to the envelope of a balloon or airship, and to which are attached the main suspensions of the basket or car, or the captive cable of a kite balloon.

trajectory—A band of webbing carried in a special curve over the surface of the envelope of an airship to distribute the stresses due to the suspension of the car.

bank—To incline an airplane laterally, i.e., to rotate it about its longitudinal axis. Right-bank is to incline the airplane with the right wing down.

Also used as a noun to describe the position of an airplane when its lateral axis is inclined to the horizontal.

bank, angle of—See ANGLE OF ROLL.

barograph—An instrument for recording the barometric or static pressure of the atmosphere.

barrage balloon—See BALLOON, BARRAGE.

barrel-type engine—See ENGINE, BARREL-TYPE.

bar, suspension—A bar to which the supporting ropes of the basket of a balloon are secured. It is also fitted with ropes and toggles for attaching to the basket suspensions from the balloon. Also called "trapeze bar."

basic load—See LOAD, BASIC.

basket—The structure suspended beneath a balloon, for carrying passengers, ballast, etc.

It is usually used on a free or kite balloon.

batonet—A special form of toggle, usually quite slender and truly cylindrical, except for the groove, and used to attach the rigging of a balloon or airship to a fabric loop or suspension band on the envelope.

bay (body parts)—The portion of a face of a truss, or of a fuselage, between adjacent bulkheads or adjacent struts or frame positions.

biplane—An airplane with two main supporting surfaces placed one above the other.

blade back—The side of a propeller blade which corresponds to the upper surface of an airfoil.

blade face—The surface of a propeller blade which corresponds to the lower surface of an airfoil. Sometimes called "thrust face," or "driving face."

blade-width ratio—The ratio of the developed width of a propeller blade at any point to the circumference of a circle whose radius is the distance of that point from the propeller axis.

blimp—A small non-rigid airship. "Airship" is to be preferred.

body—The fuselage or hull, or nacelle (including cowling and covering) and nacelle mounting.

bonnet—See HOOD, VALVE.

bow cap—See CAP, BOW.

bow-heavy—The condition of an airship which, when at rest in still air, trims with its axis inclined down by the bow. The term "bow-heavy" is preferred to "nose-heavy" in describing airships.

bow-steadying line—See LINE, YAW.

bow stiffener—See STIFFENER, BOW.

box girder—See GIRDER, BOX.

brake mean-effective pressure—The net unit pressure which, if applied during the power strokes to the pistons of an engine having no mechanical losses, would produce the given brake horsepower at the stated speed.

breathing—The passage of air into or out of an aerostat, due to the changing of its volume.

breathing stresses—See STRESSES, BREATHING.

bridle—A sling of cordage or wire which has its ends fixed at two different points, to the bight of which a single line may be attached, either movable or fixed, thus distributing the pull of the single line to two points or more in the case of a multiple bridle. This term is also used to refer to a towing or mooring line having two legs and intended to reduce yawing when towing or mooring.

building cradle—See CRADLE, BUILDING.

bullseye—A circular thimble.

buoyancy—The upward air force on an aerostat which is derived from aerostatic conditions. It is equal to the weight of the air displaced.

buoyancy, center of (aerostat)—The center of gravity of the volume of the contained gas.

C

cabane—A framework for supporting the wings at the fuselage; also applied to the system of trussing used to support overhang in a wing.

cable, axial—The axial member (usually steel wire cable) sometimes fitted in a rigid airship. It is attached to the central fitting of the radial or diametral wires of each main transverse and to the hull structure at bow and stern. Its purpose is to provide support for the radial or diametral wires in an axial direction and thus assist them to sustain the load which might be caused by unequal pressure in adjacent cells or by the airship being pitched to a large angle.

camber—The rise in the curve of an airfoil section from its chord, usually expressed as the ratio of the departure of the curve from the chord to the length of the chord. "Upper camber" refers to the upper surface of an airfoil and "lower camber" to the lower surface; "mean camber" is the mean of these two.

capacity—The volume of the gas-containing portion of an aerostat.

capacity, nominal gas—The volume of the envelope of gas cells of an aerostat under certain conditions of pressure and inflation which have been defined. It is rarely the same as the true full volume. This is

usually very difficult to determine accurately, especially in the case of rigid airships. Sometimes called "volume."

cap, bow—(1) A cap of metal or fabric used to reinforce the extreme forward ends of the bow stiffeners of a non-rigid or semi-rigid airship.

(2) The conical or cap-shaped structure at the extreme bow of a rigid airship to which the longitudinal girders are attached and which supports the bow mooring spindle.

cap, nose—See CAP, BOW, which is to be preferred.

captive balloon—See BALLOON, CAPTIVE.

car—That portion of an airship which is intended to carry power unit or units, personnel, cargo, or equipment. It may be suspended from the buoyant portion, or it may be built close up against it. It is not to be applied to parts of the keel of a rigid or semi-rigid airship which have been fitted for the purposes mentioned.

car, control—The car of an airship in which controls are centralized and from which it is operated.

carrier, fin—A frame to which the inboard edge of the fin of a non-rigid or semi-rigid airship is attached, so as to prevent the edge of the fin from sinking into the envelope.

car, side—See CAR, WING.

car, wing—A car suspended off the center line of an airship. It is also called "side car."

catenary—A line or length of cordage which is secured to or in a piece of fabric in the form of a catenary curve or a series of such curves.

ceiling:

absolute—The maximum height above sea level at which a given airplane would be able to maintain horizontal flight, assuming standard air conditions.

service—The height above sea level, assuming standard air conditions, at which a given airplane ceases to be able to rise at a rate higher than a small specified one (100 feet per minute in the United States and England). This specified rate may be different in different countries.

ceiling, static—The altitude in standard atmosphere, at which an aerostat is in static equilibrium after removal of all dischargeable weights.

cell, gas—One of the gas-containing units fitted in a rigid airship. Sometimes called "gas bag."

center of buoyancy—See BUOYANCY, CENTER OF (AEROSTAT).

center of pressure coefficient—The ratio of the distance of the center of pressure from the leading edge to the chord length.

center of pressure of an airfoil section—The point in the chord of an airfoil section, prolonged if necessary, which is at the intersection of the chord and the line of action of the resultant air force. Its abbreviation is C. P.

chafing patch—See PATCH, CHAFING.

channel patch—See PATCH, CHANNEL.

chord (of an airfoil section)—The line of a straight edge brought into contact with the lower surface of the section at two points; in the case of an airfoil having double convex camber, the straight line joining the leading and trailing edges. (These edges may be defined, for this pur-

pose, as the two points in the section which are farthest apart.) The line joining the leading and trailing edges should be used also in those cases in which the lower surface is convex except for a short flat portion.

The method used for determining the chord should always be explicitly stated for those sections with regard to which ambiguity seems likely to arise.

chord length—The length of the projection of the airfoil section on its chord. Its symbol is c.

chord, mean, of a combination of wings—The ratio—

$$\frac{c_1S_1 + c_2S_2 + c_3S_3 + \ldots\ldots}{S_1 + S_2 + S_3 +}$$

where c_1, c_2, c_3, etc., are the mean chords of various wings, and S_1, S_2, S_3, etc., are their areas.

chord, mean of a wing—The quotient obtained by dividing the wing area by the extreme dimension of the wing projection at right angles to the chord.

chord wire—See WIRE (AIRSHIP), CHORD.

climb, rate of—See RATE OF CLIMB.

climbing shaft—See SHAFT, CLIMBING.

cloth—Fabric delivered by the bleachery or finisher before it has been proofed, doped, or specially treated for aeronautic use.

cloth, ground—Canvas placed beneath an aerostat for its protection during inflation and deflation.

cockpit—The open spaces in which the pilot and passengers are accommodated. When the cockpit is completely housed in it is called a cabin.

compartment, control—A compartment in the control car of an airship from which all controls are operated. It may be compared to the pilot house of a ship.

compass, induction—A compass, the indications of which depend on the current generated in a coil revolving in the earth's magnetic field.

concentration ring—See RING, CONCENTRATION.

condenser, water-recovery—That part of the water-recovery apparatus which is devoted to the condensing of water in the exhaust gases. It may consist of a number of metal tubes or of a fabric box with appropriate inlets, outlets, and baffles.

cone, axial—The cone-shaped fabric, fitting in the end of a gas cell of a rigid airship, which provides a gas-tight connection of the cell to the axial cable and yet permits the cell some degree of freedom in its movements. A special form of conical sleeve. (Fig. 4.)

cone, danger—A pennant on the wire cable of a captive balloon to warn aircraft of its presence. Usually a hollow cone of light cloth.

cone, mooring—The grooved conical member at the extreme bow of an airship which engages with a hollow cone at the top of the mooring mast and provides the coupling between the airship and the mooring mast

conical sleeve—See SLEEVE, CONICAL.
container, gas—See CELL, GAS, which is to be preferred.
control car—See CAR, CONTROL.
control compartment—See COMPARTMENT, CONTROL.
controllability—The quality in an airplane which makes it possible for the pilot to change its attitude easily and with the exertion of but little force.
control lines—See LINES, CONTROL.
controls—A general term applied to the means provided to enable the pilot to control the speed, direction of flight, attitude, and power of an aircraft.
  air controls—The means employed to operate the control surfaces of the aircraft.
  engine controls—The means employed to control the power output of the engines. (Control of speed may be effected by the air controls or the engine controls independently, or by either in conjunction with the other.)
control stick—The vertical level by means of which the longitudinal and lateral controls of an airplane are operated. Pitching is controlled by a fore-and-aft movement of the stick, rolling by a side-to-side movement.
control surface—See SURFACE, CONTROL.
cord grommet—See GROMMET.
cord netting—See NET, GAS CELL (RIGID AIRSHIP).
cord, rip—The rope running from the rip panel to the car or basket, the pulling of which tears off or rips the rip panel and causes immediate deflation.
cover, outer—The outside covering of the hull of a rigid airship, usually of some kind of fabric. Sometimes called the "envelope."
cover, valve—See HOOD, VALVE.
cowling—A removable covering which extends over or around the engine, and sometimes over a portion of the fuselage or nacelle as well.
cradle:
  building—A support provided for the frame of a rigid airship or the keel of a semi-rigid airship during construction.
  docking—A support for the car of an airship while it is being inflated in the shed. Mostly used with rigid airships.
crew, ground—See CREW, LANDING.
crew, landing—A detail of men necessary for the landing and handling of an airship on the ground. A "ground crew."
critical angle—See ANGLE, CRITICAL.
critical speed—See SPEED, CRITICAL.
cross-country flight—See FLIGHT, CROSS-COUNTRY.
cross-wind force—See FORCE, CROSS-WIND.
crow's-foot—A system of diverging short ropes for distributing the pull of a single rope.
An arrangement in which the strands of a cord are opened out so that they can be effectively cemented to a fabric surface.
cruciform girder—See GIRDER, CRUCIFORM.

D

damping factor—The factor $e^{-\lambda t}$ in the equation of damped harmonic motion.

$$s = Ae^{-\lambda t} \sin pt.$$

danger cone—See CONE, DANGER.

dead load—See WEIGHT, EMPTY, which is to be preferred.

decalage—The acute angle between the wing chords of a biplane or multiplane. (Fig. 400.)

deflation—The act of removing gas and air from an aerostat.

deflation sleeve—See SLEEVE, DEFLATION.

diametral wire—See WIRE (AIRSHIP), DIAMETRICAL.

diaphragm, ballonet—The fabric partition between the gas and air compartments of the envelope of a non-rigid or semi-rigid airship or kite balloon.

dihedral angle—See ANGLE, WING-DIHEDRAL.

dirigible—That can be directed; steerable; as a dirigible balloon. Its use as a noun to indicate an airship is improper.

dischargeable weight—See WEIGHT, DISCHARGEABLE.

displacement—The mass of air displaced by the gas used for inflation. It may be expressed as a weight or volume. In the latter case it is usually called "volume."

displacement, aerodynamic volume of air volume—The weight of a mass of air equal to the aerodynamic volume of the airship in N. A. C. A. standard atmosphere at sea level.

disposable weight—See WEIGHT, DISPOSABLE (AIRSHIP).

dive—A steep descent, with or without power, in which the air speed is greater than the maximum speed in horizontal flight.

divergence—A motion in which, after a disturbance from equilibrium, the body departs continuously, without oscillations, from its original state of motion.

dock—A term sometimes applied to an airship shed.

docking cradle—See CRADLE, DOCKING.

docking rail—See RAIL, DOCKING.

docking trolley—See TROLLEY, DOCKING.

dope (airplane)—The liquid material applied to the cloth surfaces of airplanes to increase strength, to produce tautness by shrinking, and to act as a filler for maintaining air-tightness.

dope (airship)—The liquid material applied to rubberized airship fabric to increase gas-tightness. In contrast with airplane dope, it does not cause shrinking.

dope (pigmented)—An aircraft dope to which a pigment has been added to make an opaque finish, or to protect it from the effects of sunlight.

downwash angle—See ANGLE, DOWNWASH.

drag—The component parallel to the relative wind of the total air force on an aircraft or airfoil. Its symbol is D.

The "absolute drag coefficient" is C_D *as defined by the equation* $C_D = \dfrac{D}{qS}$,

in which D is the drag, q is the impact pressure ($= \frac{1}{2} \rho V^2$) and S is the effective area of the surface upon which the air force acts.

In the case of an airplane, that part of the drag due to the wings is called "wing drag"; that due to the rest of the airplane is called "structural drag" or "parasite resistance."

induced—That portion of the wing drag induced by, or resulting from, the generation of the lift.

profile—That portion of the wing drag which is due to friction and turbulence in the fluid and which would be absent in a non-viscous fluid.

drag, mooring—A movable and/or variable weight, suspended from the after part of an airship's structure while moored at a mast, to aid in restraining the vertical and lateral motions of the stern of the airship.

drag rope—See ROPE, DRAG.

drag strut—See STRUT, DRAG.

drift—The lateral velocity of an aircraft due to air currents.

drift angle—See ANGLE, DRIFT.

drift bar—A part of a drift meter or other instrument for indicating the apparent direction of motion of the ground relative to the fore-and-aft axis of the aircraft. It usually consists of a wire or arm which can be set along this direction of motion. Cf. drift.

drift meter—An instrument for measuring the angle between the fore-and-aft axis of an aircraft and its path over the ground. One form consists of a drift bar provided with a suitable angular scale. (Cf. drift.) The instrument is graduated to read correctly when it is level.

drip band—See FLAP, DRIP.

drip flap—See FLAP, DRIP.

drip strip—See FLAP, DRIP.

D—ring—A ring having (as the name implies) the shape of a capital D, to which rope suspensions are attached.

drogue—See ANCHOR, SEA.

dry weight of an engine—See ENGINE, DRY WEIGHT OF.

duralumin—An alloy of aluminum which is much used in aeronautics, especially for the structure of airships and airplanes. Its chemical composition and physical properties are about as follows:

Copper, 3.5 to 4.5 per cent.
Manganese, 0.4 to 1 per cent.
Magnesium, 0.2 to 0.75 per cent.
Aluminum, 92 per cent, minimum.
Tensile strength, ultimate, 55,000 pounds per square inch.
Tensile strength at elastic limit, 30,000 pounds per square inch.
Elongation of 2 inches at ultimate strength (test specimen ½ inch wide), 18 per cent.
Specific gravity not more than 2.85.

dynamic factor—The ratio between the load carried by any part of an aircraft when accelerating and the corresponding basic load.

dynamic lift—See LIFT, DYNAMIC.

dynamic load—See LOAD, DYNAMIC.

dynamic (or impact) pressure—The product $\frac{1}{2} \rho B^2$, where ρ is the density

of the air and V is the relative speed of the air. It is the quantity measured by most air-speed instruments. Symbol is q.

dynamic trim—See TRIM, DYNAMIC.

E

economic speed—See SPEED, ECONOMIC.

effective helix angle—See ANGLE, EFFECTIVE HELIX.

effective thrust—See THRUST, EFFECTIVE.

elevator—A movable auxiliary airfoil, the function of which is to impress a pitching moment on the aircraft. The elevator is usually hinged to the stabilizer.

elevator angle—See ANGLE, ELEVATOR.

endurance—The maximum length of time an aircraft can remain in the air at a given speed and altitude.

engine altimeter—See ALTIMETER, ENGINE.

engine, barrel-type—An engine having its cylinders arranged equidistant from and parallel to the main shaft.

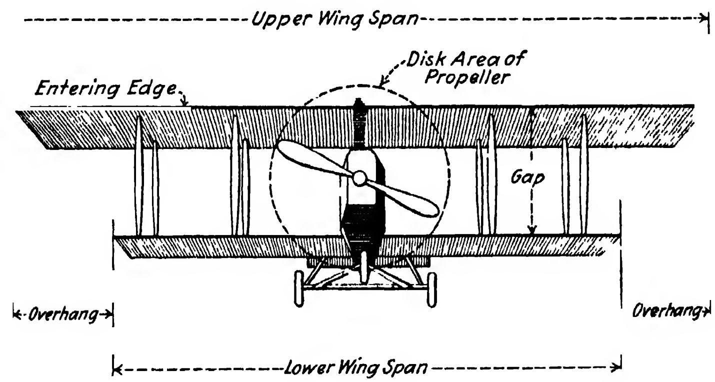


Fig. 398.—Diagram Showing Entering Edge, Span, Disc Area of Propeller, etc.

engine controls—See CONTROLS.

engine, dry weight of an—The weight of the engine, including carburetor and ignition systems complete, propeller hub assembly, reduction gears, if any, but excluding exhaust manifolds, oil, and water. If the starter is built into the engine as an integral part of the structure its weight shall be included.

engine, inverted—An engine having its cylinders below the crankshaft.

engine, left-hand—An engine whose propeller shaft, to an observer facing the propeller from the anti-propeller end of the shaft, rotates in a counterclockwise direction.

engine, radial—An engine having stationary cylinders arranged radially around a common crankshaft.

engine, right-hand—An engine whose propeller shaft, to an observer fac-

ing the propeller from the anti-propeller end of the shaft, rotates in a clockwise direction.

engine, rotary—An engine having revolving cylinders arranged radially around a common fixed crankshaft.

engine, supercharged—An engine with mechanical means for increasing the cylinder charge beyond that normally taken in at the existing atmospheric pressure and temperature.

engine, vertical—An engine having its cylinders arranged vertically above the crankshaft.

engine, V-type—An engine having its cylinders arranged in two rows, forming, in the end view, the letter "V."

engine, W-type—An engine having its cylinders arranged in three rows, forming, in the end view, the letter "W." Sometimes called the "broad-arrow type."

entering edge—See LEADING EDGE.

envelope—The outer covering of an aerostat, usually of fabric. It may or may not be also the gas container. It may be divided by diaphragms into separate gas compartments or cells, and it may also contain internal air cells or ballonets.

equipment, ground—See GEAR, GROUND.

F

fabric, balloon—The finished material, usually rubberized, of which balloon or airship envelopes are made.

biased—Plied fabric in which the threads of the plies are at an angle to each other.

parallel—Plied fabric in which the threads of the plies are parallel to each other.

fabric, gas-cell—The fabric used in gas cells of rigid airships, usually goldbeater's skin fabric, q. v.

fabric, goldbeater's skin—A gas containing fabric consisting of a layer of light, fine, strong cloth, usually cotton, to which one or more layers of goldbeater's skins have been cemented. The skins are on the inside and are usually further protected by a coat of fine varnish. Usually used in the gas cells of rigid airships.

factor, dynamic—See DYNAMIC FACTOR.

factor of safety—The ratio of the ultimate strength of a member to the maximum probable load in that member in actual use.

fairing—An auxiliary member or structure whose primary function is to reduce head resistance or drag of that part to which it is fitted (without, in general, contributing strength).

fairing wire—See WIRE, FAIRING.

field-handling frame—See FRAME, FIELD-HANDLING.

filling sleeve—See SLEEVE, FILLING.

fin—A fixed surface, attached to a part of the aircraft, parallel to the longitudinal axis, in order to secure stability; for example, a tail fin, skid fin, etc. Fins are sometimes adjustable.

fin carrier—See CARRIER, FIN.

fin girder—See GIRDER, FIN.

finger patch—See PATCH, FINGER.

fire wall—A fire-resistance transverse bulkhead, so set as to isolate the engine compartment from the other parts of the structure and thus to reduce the risk from fire in the engine compartment.

fitting—A generic term for any small part used in the structure of an airplane or airship. If without qualification, a metal part is usually understood. It may refer to other parts, such as "fabric fittings."

fixed fuel tank—See TANK, FIXED FUEL.

fixed power plant weight for a given airplane—See WEIGHT, FIXED, POWER PLANT, FOR A GIVEN AIRPLANE.

fixed surface—See FIN.

fixed weight—See WEIGHT, FIXED (AIRSHIP).

flap, drip—A strip of fabric attached by one edge to the envelope of an aerostat so that rain runs off its free edge instead of dripping into the basket or car. It also assists in keeping the suspension ropes dry and non-conducting. Also called "drip band" and "drip strip."

flap, pressure—A flap valve fitted in the outer cover or envelope of a rigid airship and arranged to permit the rapid flow of air in and out—particularly inward. The purpose is to facilitate the rapid equalization of the pressure of the air within the envelope with that of the surrounding air.

flight, cross-country—A flight which necessitates leaving the vicinity of a regular landing field.

flight indicator—See INDICATOR, FLIGHT.

flight path—The path of the center of gravity of an aircraft with reference to the earth.

flight recorder—See RECORDER, FLIGHT.

float—A completely inclosed water-tight structure attached to an aircraft in order to give it buoyancy and stability when in contact with the surface of the water. In float seaplanes the crew is carried in a fuselage or nacelle separate from the float. The term "pontoon" is now obsolete.

flotation gear—See GEAR, FLOTATION.

flying boat—A form of seaplane supported, when resting on the surface of the water, by a hull or hulls, providing flotation in addition to serving as fuselages. For the central hull type, lateral stability is usually provided by wing-tip floats. The term "boat seaplane" is now obsolete.

force, cross-wind—The component, perpendicular to the lift and to the drag, of the total air force on the aircraft or any part thereof. Its symbol is C and its absolute coefficient is C_c is defined by

$$C_c = \frac{C}{qS}$$

where q is the impact pressure ($= \frac{1}{2} \rho V^2$) and S is the effective area of the surface upon which the air force acts.

frame, field-handling—A portable frame which may be attached to an airship when it is on the ground and which is intended to afford a grasp

to more men than could get on the handling rails of the cars. These frames are rarely carried when in flight.

framing, stern—All framework, aft of the cruciform girder, necessary to complete the shape and contour of a rigid airship.

free balloon—See BALLOON, FREE.

free-balloon net—See NET, FREE-BALLOON.

fuel (or oil) consumption, specific—The weight of fuel (or oil) consumed per brake horsepower hour.

fuel tank, fixed—See TANK, FIXED FUEL.

full load—See LOAD, FULL.

fuselage—The structure, of approximately streamline form, to which are attached the wings and tail unit of an airplane. In general it contains the power plant, passengers, cargo, etc.

fuselage, monocoque—A type of fuselage construction wherein the structure consists of a thin shell of wood, metal, or other material, supported by ribs, frames, belt frames, or bulkheads, but usually without longitudinal members other than the shell itself. The whole is so disposed as to carry the stresses to which the structure is subjected.

G

gap—The distance between the planes of the chords of any two adjacent wings, measured along a line perpendicular to the chord of the upper wing at any designated point of its leading edge. Its symbol is G.

gas bag—See HULL (AIRSHIP) and CELL, GAS.

gas capacity, nominal—See CAPACITY, NOMINAL GAS.

gas cell—See CELL, GAS.

gas-cell alarm—See ALARM, GAS-CELL.

gas-cell fabric—See FABRIC, GAS-CELL.

gas-cell net—See NET, GAS-CELL (RIGID AIRSHIP).

gas container—See CELL, GAS.

gas shaft—See SHAFT, GAS.

gas-shaft hood—See HOOD, GAS-SHAFT.

gassing—The operation of replenishing a balloon with fresh gas to increase the purity or to make up for loss of gas.

gassing factor—The quantity of aerostatic gas required to maintain an aerostat for one year. It is ordinarily expressed as a percentage of the gas volume.

gas volume—See VOLUME, GAS (AIRSHIP).

gear, flotation—An emergency gear attached to a landplane to permit alighting on the water and to provide buoyancy when resting on the surface of the water.

gear, ground—The gear, or equipment, necessary for the landing and handling of an airship on the ground.

girder, box—Any girder of rectangular section. Frequently used to refer to the rectangular, longitudinal members in the keel of a rigid airship from which fuel tanks and gas bags are suspended.

girder, cruciform—The structure, consisting of vertical and horizontal transverse girders, which is fitted at the stern of a rigid airship for the

purpose of supporting the inboard ends of the stern posts of the fins or the rudder posts. It may be integral with the stern posts which form the after ends of the fins.

girder, fin—A girder of a rigid airship which goes to make up the fin.

girder, propeller reinforcing—A light additional member fitted in the structure of a rigid airship to reinforce those areas of the outer cover which are affected by the propeller wash.

girder, walkway—The girder forming the support of a walkway through the keel or in other localities in a rigid or semi-rigid airship.

gland—A short tube fitted to an envelope or gas bag in such a manner that a rope or line may slide through without leakage of gas or air.

gland, manometer-tube—A gland fitted to the envelope of an aerostat to form a gas-tight connection for the tube leading to the manometer in the car. Same as "pressure-tube gland."

gland, pressure-tube—See GLAND, MANOMETER-TUBE.

glide—A descent with reference to the air at a normal angle of attack and without engine power sufficient for level flight in still air, the propeller thrust being replaced by a component of gravity along the line of flight. Also used as a verb.

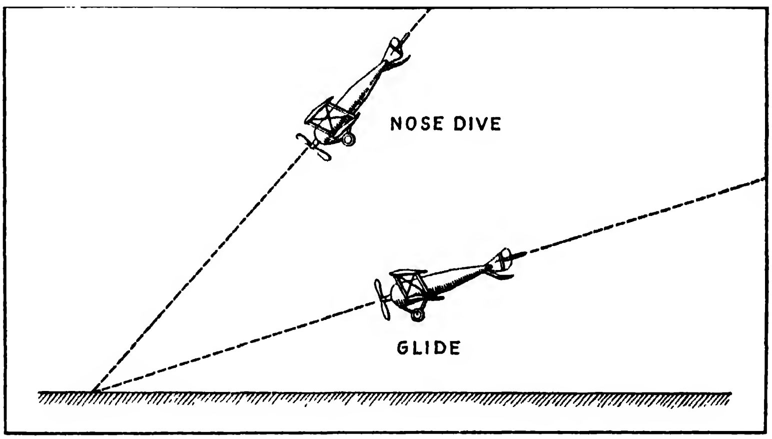


Fig. 399.—Diagrams Outlining Difference between Nose Dive and Glide.

glider—A form of aircraft similar to an airplane, but without a power plant.

goldbeater's-skin fabric—See FABRIC, GOLDBEATER'S-SKIN.

gondola—The car of an airship. This use of the word is borrowed from the Italian via the German. "Car" is to be preferred.

gore—The portion of the envelope of a balloon or airship included between two adjacent meridian seams.

grab line—See LINE, HANDLING.

grommet—A small ring of cord.

gross lift (airship)—See LIFT, GROSS (AIRSHIP).

ground angle—See ANGLE, LANDING.

ground cloth—See CLOTH, GROUND.

ground crew—See CREW, LANDING.

ground equipment—See GEAR, GROUND.
ground gear—See GEAR, GROUND.
ground speed—See SPEED, GROUND.
ground-speed meter—An instrument for measuring the speed of an aircraft relative to the ground. In present types of instruments some reference line in the instrument must first be set parallel to the apparent direction of motion of the aircraft with reference to the ground before the speed measurement is made. This is usually accomplished by the use of a drift meter, the adjustment of which automatically orients the ground-speed meter properly. Thus both the magnitude and direction of the motion of the aircraft with reference to the ground are obtained.
guy, yaw—See LINE, YAW.
gyroscopic turn indicator—See INDICATOR, GYROSCOPIC TURN.

H

handling line—See LINE, HANDLING.
hangar—A shelter for housing aircraft. More properly applied to heavier-than-air craft.
harness, mooring—A system of webbing bands, fitted over the top of the envelope of a balloon, to which are attached the mooring ropes. Usually found only in kite balloons or observation balloons.
height, pressure—The altitude at which the gas cells of a rigid airship are full, or the gas bag of a non-rigid airship is completely full of gas.
helicopter—A form of aircraft whose sole support in the ai is derived directly from the vertical component of the thrust produced by rotating airfoils.
hog—A distortion of an airship in which the longitudinal axis becomes convex upward so that both ends droop.
hood, gas-shaft—A hood, or cowl, located on the outer cover of a rigid airship at the outer end of a gas shaft. It is usually made of light wood and fabric and is faced to facilitate the escape of gas. Sometimes called "exhaust-gas hood."

In view of the possibility of confusion with the parts of an engine exhaust system, it is believed that "gas-shaft hood" is to be preferred.
hood, maneuvering-valve—A hood, or cowl, located on the outer cover of a rigid airship just over a maneuvering valve. It is usually made of light wood or fabric and is faced to facilitate the escape of gas.
hood, valve—The appliance, having the form of a hood or parasol which protects the valve of an airship or balloon against rain. Also called "valve cover" or "bonnet."
horn—A short lever attached to a control sufrace of an aircraft. For example, aileron horn, rudder horn, elevator horn.
horsepower of an engine, maximum—The maximum horsepower which an engine can develop.
horsepower of an engine, rated—The average horsepower developed by an engine of a given type in passing the standard 50-hour endurance test.
hull (airship)—The main structure of a rigid airship, consisting of a cov-

ered elongated framework which incloses the gas cells and supports the cars and equipment. May also be applied to the complete buoyant unit of any aerostat. In this latter sense sometimes called "gas bag."

hull (seaplane)—The portion of a flying boat which furnishes buoyancy when in contact with the surface of the water. It contains accommodations for the crew and passengers, usually incorporating the functions of a float and fuselage in one unit.

I

impact pressure—See DYNAMIC (OR IMPACT) PRESSURE.

iclinometer—An instrument for indicating the attitude of an aircraft. Inclinometers are termed fore-and-aft, lateral, or universal, according as they indicate inclination on the vertical plane through the fore-and-aft axis, or in the vertical plane through the lateral axis, or in both planes, respectively.

inclinometer, absolute—An instrument which indicates the attitude of an aircraft with reference to the vertical. The indications of instruments of this type usually depend on gyroscopic action.

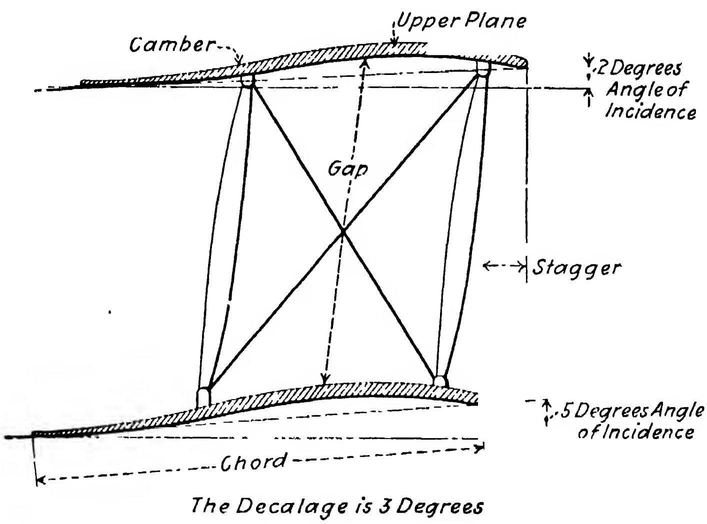


Fig. 400.—Diagram Illustrating Definitions of Decalage and Other Terms.

inclinometer, relative—An instrument which indicates the attitude of an aircraft with reference to apparent gravity, i.e., to the resultant of the acceleration of the aircraft and that due to gravity.

indicator, air-speed—See AIR-SPEED METER.

indicator, balloonet-fullness—An instrument for indicating the volume of air in a ballonet.

indicator, flight—An instrument in which a lateral inclinometer, a fore-and-aft inclinometer, and a turn indicator are combined to form a compact unit.

indicator, gyroscopic turn—A turn indicator dependent on gyroscopic action.

indicator, pitch—An instrument for indicating the existence of a pitching velocity of an aircraft. Cf. turn indicator.

indicator, static turn—A turn indicator actuated by the difference in pressure between static tubes mounted near the wing tips equidistant from the plane of symmetry, and in a plane parallel to the lateral axis.

indicator, turn—An instrument for indicating the existence of an angular velocity of turn of an aircraft about the normal axis. In horizontal flight it indicates the presence of a yawing velocity. "Turn meter" is the term applied to certain types.

indraft (inflow)—The flow of air from in front of the propeller into the blades.

induced drag—See DRAG, INDUCED.

induction compass—See COMPASS, INDUCTION.

inflation—The act of filling a balloon or airship with gas.

inflation manifold—See MANIFOLD, INFLATION.

inflation net—See NET, INFLATION.

inflation sleeve—See SLEEVE, INFLATION.

inflation tube—See TUBE, INFLATION.

inflow—See INDRAFT.

inspection window—See WINDOW, INSPECTION.

intermediate longitudinal—See LONGITUDINAL, INTERMEDIATE.

intermediate transverse—See TRANSVERSE, INTERMEDIATE.

inverted engine—See ENGINE, INVERTED.

J

jackstay—A longitudinal rigging provided to maintain the correct distance between various parts on fittings on an aerostat.

K

keel (airship)—The assembly of members at the bottom of the hull of a semi-rigid or rigid airship which provides special strength to resist hogging and sagging and also serves to distribute the effect of concentrated loads along the hull. It may be a simple Gall's chain, as in some semi-rigids, or a very extensive structure inclosing the corridor, as in most rigids.

king-post—The main compression member of a trussing system applied to support a single member subject to bending.

kite—An aircraft heavier than air, restrained by a tow-line and sustained by the relative wind.

kite balloon—See BALLOON, KITE.

kymograph—An instrument for recording the angular oscillations of an aircraft in flight with respect to axes fixed in space. The reference direction is usually given by a gyroscope or a beam of sunlight.

L

laminated wood—See WOOD, LAMINATED.

landing angle—See ANGLE, LANDING.

landing crew—See CREW, LANDING.

landing field—A field of such a size and nature as to permit of aircraft landing and taking off in safety. It may or may not be part of an airport.

landing field, emergency—A locality, either of water or land, which is adapted for the landing and taking off of aircraft, but which is not equipped with facilities for shelter, supply, and repair of aircraft and is not used regularly for the receipt or discharge of passengers or cargo by air.

landing gear—The understructure which supports the weight of an aircraft when in contact with the surface of the land or water and reduces the shock of landing. There are five common types—boat type, float type, skid type, and ski type. (Figs. 1, 6, 9, 10, and 14.) (Amphibian may be a combination of the float or boat type with wheels or skis.)

landing speed—See SPEED, LANDING.

landing T—A large symbol shaped like a capital T which is laid out on a landing field or on the top of a building to guide operators of aircraft in landing and taking off.

landing wire—See WIRE, LANDING.

landplane—An airplane designed to rise from and alight on the land. (Figs. 1, 6, and 14.)

leading edge—The foremost edge of an airfoil or propeller blade. Also called "entering edge."

leak detector—An instrument which detects the presence of hydrogen and other light gases in the air, and which can be adapted to find leaks in a container inflated with such a gas.

left-hand engine—See ENGINE, LEFT-HAND.

left side (engine)—That side which, to an observer looking from the anti-propeller end toward the propeller end, lies on the left-hand side.

lift—That component of the total air force on an aircraft or airfoil which is perpendicular to the relative wind and in the plane of symmetry. It must be specified whether this applies to a complete aircraft or to parts thereof. In the case of an airship, this is often called "dynamic lift." Its symbol is L.

The "absolute lift coefficient" is C_L as defined by the equation

$$C_L = \frac{L}{qS}$$

in which L is the lift, q is the impact pressure ($= \frac{1}{2} \rho V^2$) and S is the effective area of the surface upon which the air force acts.

lift (of a gas)—The difference of density of air and the gas. Both supposed to be under the same conditions of pressure, temperature, etc.

lift, dynamic—The lift impressed on an aerostat by aerodynamic forces.

lift, gross (airship)—The lift obtained from a volume of buoyant gas equal to the nominal gas capacity of the aircraft. Obtained by multiplying the nominal gas capacity by the lift per unit volume of the gas used for inflation.

lift, static (aerostat)—The resultant upward force on an aerostat at rest obtained by multiplying the actual volume of the air displaced by the density of the air and subtracting the weight of the contained gas.

(The volume of the air displaced, multiplied by the difference of density of the air and the contained gas.)

lift, useful (airship)—The lift available for carrying fuel, and oil, passengers, cargo, food, and drinking water, guns, ammunition, and bombs. Usually determined by deducting from the gross lift all fixed weights; certain allowances of ballast, fuel, and oil; water; spares and tools; crew and equipment. No standard has as yet been established.

lift wire—See WIRE, LIFT.

line, bow-steadying—See LINE, YAW.

line, grab—See LINE, HANDLING, and ROPE, DRAG.

line, handling—A line attached along the side of an airship for use in maneuvering near and on the ground. Sometimes called "grab line."

line, main hauling—Same as MAIN MOORING LINE.

line, main mooring—The line dropped from the bow of an airship to be coupled to the mast main mooring line.

line, mast bow-steadying—See LINE, MAST YAW.

line, mast main hauling—Same as MAST MAIN MOORING LINE.

line, mast main mooring—A line led from the main winch of a mooring mast through the mooring attachment at the top of the mast and carried out to a point on the ground well to leeward of the mast. The airship's main mooring line is attached to this line and the airship is hauled to the mast by means of the joined lines. Sometimes called "ground wire"—British.

line, mast yaw—One of the lines led from a winch at the base of the mooring mast through snatch blocks and carried out to leeward of the mast. The airship's yaw lines are attached to these lines. The snatch blocks are fixed to anchorages selected so that the joined lines tend to keep the airship into the wind and prevent her overriding the mast. These lines are also sometimes called "mast yaw guys" or "mast bow-steadying lines."

line, mooring—A line attached near the bow of an airship for securing it to the ground or to a mooring mast.

line, nose-steadying—See LINE, YAW, which is to be preferred.

line, sandbag—A rope extending along the line of suspension ropes or bridles of a kite balloon to which are hooked the sandbags used in mooring the balloon. The purpose is to prevent wear on the suspension cordage.

lines, control—The lines of wire and/or stranded cable leading from the control car or compartment to the various parts of an airship and operating (either through mechanisms or directly) the rudders, valves, etc., which control the speed, altitude, etc., of the airship.

line, suspension—A line either of cordage or metal, which supports the weight attached to the envelope of a balloon or airship.

line, yaw—A line dropped from the bow of an airship, when mooring to the mast, to act as a steadying line to prevent yawing and overriding the mast. Also called "bow-steadying line" or "yaw guy." ("Side guy wire"—British.)

load:

dead—See WEIGHT, EMPTY.

full—Weight empty plus useful load. Also called "gross weight."
pay—That part of the useful load from which revenue is derived, viz., passengers and freight.
useful—The crew and passengers, oil, and fuel, ballast other than emergency, ordnance, and portable equipment.

load, basic—The load on an aircraft when it is at rest or in a condition of unaccelerated recti-linear flight. (For purposes of stress analysis.)

load, dynamic—Any load due to accelerations of an aircraft, and therefore proportional to its mass.

load factor—The ratio of any specified load on a member to the corresponding basic load. Generally applied to the ratio of the breaking load to a basic load.

load ring—See RING, CONCENTRATION.

loading, power—The gross weight of an airplane, fully loaded, divided by the normal brake horsepower of the engine computed for air of standard density unless otherwise stated.

loading, wing—The gross weight of an airplane, fully loaded, divided by the area of the supporting surface. The area used in computing the wing loading should include ailerons, but not the stabilizer and elevators.

lobe—An air or gas inflated bag fitted at the stern of a kite balloon and acting as a fin or stabilizer to give it aerodynamic stability.

logarithmic decrement—The natural logarithm of the ratio of two successive amplitudes in a damped harmonic motion. It is equal to the product λT, where λ is the coefficient appearing in the damping factor of damped harmonic motion and T is the period of the motion.

longeron—A fore-and-aft member of the framing of an airplane fuselage or nacelle, usually continuous across a number of points of support.

longitudinal dihedral angle—See ANGLE, LONGITUDINAL DIHEDRAL.

longitudinal, intermediate—An intermediate longitudinal strength member of a rigid airship, which lies between two adjacent main longitudinals and is generally of lighter weight and/or smaller dimension than the main longitudinals.

longitudinal, main—A main longitudinal strength member, of a rigid airship, which connects the various transverse frames.

loop, mooring—See LOOP, SANDBAG.

loop, safety—A loop formed in a rip cord and attached to a securing patch by a breakable cord or a spring clip. It may be formed either inside the envelope and close to the rip panel or outside the envelope near the gland by which the rip cord passes through the envelope. Before the rip panel can be "pulled" the breakable cord must be broken or the clip opened. Accidental "pulling" is thus made unlikely, as the weight of the cord is easily carried by the breakable cord or spring clip.

loop, sandbag—A system of cordage loops on the envelope of a balloon for suspending sandbags. See also LINE, SANDBAG.

M

main hauling line—See LINE, MAIN MOORING.

main longitudinal—See LONGITUDINAL, MAIN.

main mooring line—See LINE, MAIN MOORING.
main mooring line, mast—See LINE, MAST MAIN MOORING.
main shear wire—See WIRE (AIRSHIP), MAIN SHEAR.
main supporting surface—See SURFACE, MAIN SUPPORTING.
main transverse—See TRANSVERSE, MAIN.
maneuverability—That quality in an aircraft which makes it possible for the pilot to change its attitude rapidly.
maneuvering valve—See VALVE, MANEUVERING.
maneuvering-valve hood—See HOOD, MANEUVERING-VALVE.
manhole, appendix—An appendix of large diameter and usually rather short. It is used more for access than for inflation or deflation.
manifold, inflation—A metal or fabric connection with numerous inlets which permits the passage of gas at the same time from a number of sources (either cylinders or gas holders) to the main inflation tube.
manometer pressure—See PRESSURE, MANOMETER (AEROSTAT).
manometer-tube gland—See GLAND, MANOMETER-TUBE.
mast bow-steadying line—See LINES, MAST YAW.
mast main hauling line—See LINE, MAST MAIN MOORING.
mast main mooring line—See LINE, MAST MAIN MOORING.
mast, mooring—A mast or tower at the top of which there is mounted a fitting, so that the bow of an airship may be secured. It is usually provided with a ladder or staircase and a platform at the top, so that crew and passengers may enter or leave the airship, and also with piping for the supply of fuel, gas, and water. Sometimes called "mooring tower."
mast yaw line—See LINE, MAST YAW.
meter, air-speed—See AIR-SPEED METER.
meter, ground-speed—See GROUND-SPEED METER.
meter, superheat—An instrument for measuring the difference in temperature between the gas in a gas container of a lighter-than-air craft and the surrounding air.
minimum gliding angle—See ANGLE, MINIMUM GLIDING.
minimum speed—See SPEED, MINIMUM.
monocoque fuselage—See FUSELAGE, MONOCOQUE.
monoplane—An airplane which has but one main supporting surface, sometimes divided into two parts by the fuselage.
mooring band—See BAND, MOORING.
mooring cone—See CONE, MOORING.
mooring-cone outrigger—See OUTRIGGER, MOORING-CONE.
mooring drag—See DRAG, MOORING.
mooring harness—See HARNESS, MOORING.
mooring line—See LINE, MOORING.
mooring loop—See LOOP, SANDBAG.
mooring mast—See MAST, MOORING.
mooring ring—See RING, MOORING.
mooring rope—See ROPE, MOORING.
mooring, three-point—A system of mooring an airship. It consists primarily of three lines running from a mooring ring (or point) on the airship to three points on the ground. These points are usually at the

vertices of an equilateral triangle. The lines may be secured to anchorages at the points, or run over snatch blocks and to equalizing gear. The endeavor is to moor the airship in such a manner that the dynamic lift, due to the relative wind, shall keep the airship at a constant height from the ground. May be considered as a substitute for a mooring mast, usually an emergency substitute.

mooring tower—See MAST, MOORING.

multiplane—An airplane with two or more main supporting surfaces placed one above another.

N

nacelle—An inclosed shelter for passengers or for a power plant. A nacelle is usually shorter than a fuselage, and does not carry the tail unit.

net:

free-balloon—A rigging made of ropes and twine shaped to the upper surface of the envelope, which supports the weight of the basket, etc., and distributes the load over the entire upper surface of the envelope.

gas-cell (rigid airship)—A netting of cord of small mesh which is intended to assist tthe fabric of the gas cells in transmitting gas force to a wire netting of coarser mesh and to the longitudinals, both being fiteed between the longitudinals. It may be compared to the net of a free balloon. Sometimes called "gas-cell netting" or "cord netting."

inflation—A rectangular net of cordage used to restrain the envelope of a kite balloon or airship during inflation. Also applied to a free-balloon net designed to be removed after inflation.

netting cord—See NET, GAS CELL (RIGID AIRSHIP).

netting wire—See WIRE (AIRSHIP), NETTING.

nominal gas capacity—See CAPACITY, NOMINAL GAS.

non-rigid airship—See AIRSHIP, NON-RIGID.

nose (airship)—Sometimes used for bow.

nose batten—See STIFFENER, BOW.

nose cap—See CAP, BOW, which is to be preferred.

nose-heavy—The condition of an airplane in normal flight when the distribution of forces is such that, if the longitudinal controls were released, the nose would drop.

nose-heavy (airship)—See BOW-HEAVY.

nose-steadying line—See LINE, YAW.

nozzle, pressure—An instrument which, in combination with a gauge, is used to measure the indicated speed of an aircraft relative to the air. It may be a Pitot-tube or a Venturi tube, or a combination of a Pitot tube and a Venturi tube.

nurse balloon—See BALLOON, CONSTANT PRESSURE.

nursing tube—See TUBE, SUPPLY.

observation balloon—See BALLOON, OBSERVATION.

observation platform—See PLATFORM, OBSERVATION.

optical altimeter—See ALTIMETER, OPTICAL.

ornithopter—A form of aircraft heavier than air, deriving its chief support and propelling force from flapping wings.

oscillation, phugoid—A long-period oscillation characteristic of the dis-

turbed longitudinal motion of an aircraft. This is referred to when it is said that an aircraft "hunts."

oscillation, stable—An oscillation whose amplitude does not increase.

oscillation, unstable—An oscillation whose amplitude increases continuously until an attitude is reached from which there is no tendency to return toward the original attitude, the motion becoming a steady divergence.

outer cover—See COVER, OUTER.

outrigger, mooring-cone—The member, usually tubular, which supports the mooring cone at the bow of the airship. Sometimes referred to as "mooring spindle."

over-all length—The distance from the extreme front to the extreme rear of an aircraft, including the propeller and the tail unit.

overhang—Used in two senses. (1) one-half of the difference in span of any two main supporting surfaces of an airplane. The overhang is positive when the upper of the two main supporting surfaces has the larger span. (2) The distance from the outer strut attachment to the tip of the wings.

overhead suspension—See SUSPENSION, OVERHEAD.

pancake, to—To level off an airplane at a greater altitude than normal in a landing, thus causing it to stall and to descend on a steeply inclined path with the wings at a very large angle of attack and without appreciable bank.

panel (aerostat)—The unit piece of fabric of which the envelope or outer cover of an aerostat is made. Panels may be assembled into sections, gores, or rings, according to the method of manufacture followed.

In rigid airships the area bounded by two adjacent longitudinals and two adjacent transverses is often referred to as a "panel." This is a structural panel and the expression is borrowed from structural engineers.

panel, rip—A strip of fabric inserted or fitted in the upper part of the envelope of a balloon or semi-rigid or non-rigid airship which is torn or ripped open when immediate deflation is desired.

panel (wing parts)—Where a wing surface comprises several units of construction, these units are designated as panels.

parasite resistance—See DRAG.

patch—A strengthened or reinforced flap or fabric of special shape and construction, which is cemented to the envelope or gas cell. It usually forms an anchor by which some portion of the structure may be attached to the envelope, or by which the positioning lines controlling the gas cell, may be attached to the cell.

patch, chafing—A patch of fabric secured to the envelope of an aerostat to protect it from abrasion.

patch, channel—A channel-shaped fabric-fitting secured to the envelope of an aerostat to allow a rod or spar to be laced to the envelope.

patch, finger—A special form of patch having extensions or "fingers" ex-

tending out from the central portion. The "fingers" may be of tape, frayed out rope, or fabric. Their function is to distribute the load more widely to the fabric of the envelope or gas cells.

patch, suspension—A patch, secured to the envelope or to a gas cell of an aerostat, to which a suspension line may be attached.

pay-load—See LOAD, PAY.

pendant, sighting—A vertical wire on center line and forward of the control car of an airship, used as a mark in steering, to assist in determining wind direction.

performance testing—See TESTING, PERFORMANCE.

period—The time taken for a complete oscillation.

permeability—The measure of the rate of diffusion of gas through intact balloon fabric; usually expressed in liters of hydrogen per square meter of fabric per 24 hours, under standard conditions of pressure and temperature.

phugoid oscillation—See OSCILLATION, PHUGOID.

pigmented dope—See DOPE (PIGMENTED).

pilot—An operator of aircraft. This term is applied regardless of the sex of the operator.

pilot balloon—See BALLOON, PILOT.

pitch, angle of—See ANGLE OF PITCH.

pitch indicator—See INDICATOR, PITCH.

pitch of a propeller:

effective—The distance which an aircraft advances along its flight path for one revolution of the propeller. Its symbol is p_e.

geometrical—The distance which an element of a propeller would advance in one revolution, if it were moving along a helix of slope equal to its blade angle.

mean geometrical—The mean of the geometrical pitches of the several elements. Its symbol is p_g.

standard—The geometrical pitch taken at two-thirds of the radius. Also called "nominal pitch." Its symbol is p_s.

zero thrust—The distance which a propeller would have to advance in one revolution in order that there might be no thrust. Also called "experimental mean pitch." Its symbol is p_v.

zero torque—The distance which a propeller would have to advance in one revolution in order that the torque might be zero. Its symbol is p_a.

pitch ratio—The ratio of the pitch (geometrical, unless otherwise stated) to the diameter p/D.

pitch speed—The product of the mean geometrical pitch by the number of revolutions of the propeller in unit time—i.e., the speed the aircraft would make if there were no slip.

Pitot tube—A cylindrical tube with an open end which is pointed upstream (i.e., so that the air meets the instrument head-on or is met head-on by the instrument). When the aircraft is flying less than about 200 miles per hour, the instrument measures the impact pressure. When used on aircraft, it is usually associated either with a closed coaxial tube

surrounding it or with a closed tube placed near it and parallel to it, the combination being termed a Pitot-static tube. The associated tube has perforations in its side so that it is subjected to static pressure, as distinct from impact pressure. The speed of the fluid can be determined from the difference between the impact pressure and the static pressure as read by a suitable gauge. In common terminology the Pitot-static combination, as above, is often termed simply at Pitot tube or Pitot.

platform, observation—A platform or small deck fitted on the top of an airship and used as a post for a lookout and defense or as a place from which to make observations used in navigating the airship.

plywood—A product formed by gluing together two or more layers of veneer. The alternate plies are usually placed with grain at right angles to the adjacent plies.

pontoon (now obselete)—See FLOAT.

power loading—See LOADING, POWER.

pressure alarm—See ALARM, GAS-CELL.

pressure, dynamic—See DYNAMIC (OR IMPACT) PRESSURE.

pressure flap—See FLAP, PRESSURE.

pressure height—See HEIGHT, PRESSURE.

pressure, manometer (aerostat)—The excess of pressure inside the envelope of an aerostat over the atmospheric pressure at a standard reference point. The point of reefrence for the excess of pressure is usually the bottom of the envelope or gas cell for airships and the level of the basket for kite balloons.

pressure nozzle—See NOZZLE, PRESSURE.

pressure-relief vent—See VENT, PRESSURE-RELIEF.

pressure tube—See TUBE, PRESSURE.

pressure-tube gland—See GLAND, MANOMETER-TUBE.

profile—See AIRFOIL SECTION (OR PROFILE).

profile drag—See DRAG.

proofing—Material incorporated in the fabric of an aerostat at the time of manufacture to increase its resistance to the weather and/or to prevent the passage of gas (or decrease its permeability).

propaganda balloon—See BALLOON, PROPAGANDA.

propeller:

adjustable pitch—A propeller whose blades are so attached to the hub that they may be set to any desired pitch when the propeller is stationary.

controllable pitch or variable pitch—A propeller whose blades are so mounted that they may be turned about their axis to any desired pitch while the propeller is in rotation.

propeller area, projected—The total area in the plane perpendicular to the propeller shaft swept by the propeller, excepting the portion covered by the boss and that swept by the root of the blade. This portion is usually taken at extending 0.2 of the maximum radius from the axis of the shaft.

propeller blade—See BLADE FACE; BLADE BACK; BLADE-WIDTH RATIO.

propeller-blade angle—See ANGLE, PROPELLER-BLADE.

propeller-blade area—The area of the blade face, exclusive of the boss and the root, i.e., of a portion which is usually taken as extending 0.2 of the maximum radius from the axis of the shaft.

propeller boss—The central portion of a propeller in which the hub is formed or mounted.

propeller-camber ratio—The ratio of the maximum thickness of a propeller section to its chord.

propeller-disk area, total—The total area swept by a propeller, i.e., the area of a circle having a diameter equal to the propeller diameter.

propeller efficiency—The ratio of thrust power to power input of a propeller. Its symbol is η.

propeller hub—The metal fitting inserted or incorporated in or with a propeller for the purpose of mounting it on the propeller or engine shaft.

propeller interference—The amount by which the torque and thrust of a propeller are changed by the modification of the airflow in the slipstream produced by bodies placed near the propeller, such as engine, radiator, etc.

propeller-load curve—A curve representing the engine power necessary to drive any given propeller at various speeds. The power required varies approximately as the cube of the speed in R. P. M., provided the ratio $\frac{V}{ND}$ remains constant.

propeller pitch—See PITCH OF A PROPELLER.

propeller, pusher—A propeller mounted to the rear of the engine or propeller shaft. (It is usually behind the wing cell or nacelle.)

propeller rake—The mean angle which the line joining the centroids of the sections of a propeller blade makes with a plane perpendicular to the axis.

propeller reinforcing girder—See GIRDER, PROPELLER REINFORCING.

propeller root—That part of the propeller blade near the boss.

propeller section—A cross section of a propeller blade made at any point by a plane parallel to the axis of rotation of the propeller and tangent at the centroid of the section to an arc drawn with the axis of rotation as its center.

propeller thrust—The component parallel to the propeller axis of the total air force on the propeller. Its symbol is T.

propeller torque—The moment applied to the propeller by the engine shaft. Its symbol is Q.

propeller, tractor—A propeller mounted on the forward end of the engine or propeller shaft. (It is usually forward of the fuselage or wing nacelle.)

propeller-width ratio, total—The product of blade-width ratio at the point of maximum blade width by number of blades.

propulsive efficiency—The ratio of the product of effective thrust and flight speed to the actual power input to the propeller as mounted on the airplane, consistent units being used throughout.

purity (of gas)—The ratio of the pressure of the hydrogen (or other aerostatic gas) in the container to the total pressure due to all the contained gases.

pusher airplane—See AIRPLANE, PUSHER.

pusher propeller—See PROPELLER, PUSHER.

Q

quadrant—The operating lever, made on the arc of a circle, of a control surface of an airship, e.g., rudder quadrant, elevator quadrant.

quadruplane—An airplane with four main supporting surfaces, placed one above another.

R

race rotation—The rotation, produced by the action of the propeller, of the stream of air passing through or influenced by the propeller.

radial engine—See ENGINE, RADIAL.

radial wire—See WIRE (AIRSHIP), RADIAL.

rail, docking—A rail or guide, constructed on the landing field and extending into the shed, which supplies a means for holding the lateral pull of an airship's docking or handling lines. The pull is transmitted to the rails from wheeled cars or trolleys which are fitted on or in the rails. Usually two rails are fitted at the greatest distance apart which will permit them to be run into the shed.

rake, propeller—See PROPELLER RAKE.

ram—The combination of tubes and springs which is mounted in gimbals at the top of a mooring mast. It consists of an outer tube which carries the gimbal mounting and within which slides an inner tube. The upper end of the inner tube carries the hollow cone which receives the airship's mooring cone and which is fitted to revolve freely. The inner tube can slide down into the outer tube and compress heavy springs, thus easing the shock when the mooring is made.

range at economic speed—The maximum distance a given aircraft can cover while cruising at the most economical speed and altitude at all stages of the flight.

range at full speed—The maximum distance a given aircraft can cover at full speed at sea level.

rate of climb—The vertical component of the air speed of an aircraft, i.e., its vertical velocity with reference to the air.

recorder, flight—An instrument for recording certain elements of the performance of an aircraft.

relative inclinometer—See INCLINOMETER, RELATIVE.

relative wind—See WIND, RELATIVE.

resistance derivatives—Quantities expressing the variation of the forces and moments on aircraft due to disturbance of steady motion. They form the experimental basis of the theory of stability, and from them the periods and damping factors of aircraft can be calculated. In the general case there are 18 translatory and 18 rotary derivatives.

lateral—Resistance derivatives expressing the variation of moments and forces due to small changes in the lateral, yawing, and rolling velocities.

longitudinal—Resistance derivatives expressing the variation of moments and forces due to small changes in the longitudinal, normal, and pitching velocities.

rotary—Resistance derivatives expressing the variation of moments and forces due to small changes in the rotational velocities of the aircraft.

translatory—resistance derivatives expressing the variation of moments and forces due to small changes in the translational velocities of the aircraft.

restoring moment—See RIGHTING MOMENT.

reverse turn—See TURN, REVERSE.

revolutions, maximum—The number of revolutions per minute corresponding to the maximum horsepower.

revolutions, rated—The number of revolutions corresponding to the rated horsepower.

Reynolds Number—A name given the fraction $p\frac{Vl}{u}$ in which

p is the density of the fluid;
V is the relative velocity of the fluid;
l is the linear dimension of the body;
u is the coefficient of viscosity of the fluid.

rigger—One who is employed is assembling and aligning aircraft.

rigging (aerostat)—The attachment and adjustment of the car, rudders, valves, controls, etc., of an airship.

rigging, (airplane)—The assembling, adjusting, and aligning of the parts of an airplane.

right-hand engine—See ENGINE, RIGHT-HAND.

righting moment (or restoring moment)—A moment which tends to restore an aircraft to its previous attitude after any small rotational displacement.

right side (engine)—That side which, to an observer looking from the anti-propeller end toward the propeller end, lies on the right-hand side.

rigid airship—See AIRSHIP, RIGID.

ring, concentration:

airship—A ring to which several rigging lines are led from the envelope and from which one or more lines also lead to the car.

free balloon—A ring to which are attached the ropes suspending the basket and to which the net is also secured. Sometimes called "load ring."

ring, load—See RING, CONCENTRATION (FREE BALLOON).

ring, mooring—A metallic ring suspended from one of the forward frames of a rigid airship by wire lines and used for mooring. The vertex of a "three-point mooring" is attached to this ring.

rip cord—See CORD, RIP.

rip panel—See PANEL, RIP.

roll—A maneuver in which a complete revolution about the longitudinal axis is made, the horizontal direction of flight being approximately maintained.

roll, angle of—See ANGLE OF ROLL.

rope, drag—A long rope which can be hung overboard from a balloon so as to act as a brake and a variable ballast in making a landing. Same as "trail rope" or "guide rope." On airships a similar rope or ropes is used as a haul-down or mooring line by the landing crew. It is usually larger and longer than a regular handling line. Sometimes called "grab line."

rope, mooring—A line attached to a balloon or airship for use in securing it to the ground. It may serve the purpose of a "handling line," or vice versa.

rope, trail—See ROPE, DRAG.

rotary engine—See ENGINE, ROTARY.

rudder—A movable auxiliary airfoil, the function of which is to impress a yawing moment on the aircraft in normal flight. It is usually located at the rear of an aircraft.

rudder (airship)—A hinged or pivoted surface, usually attached to a fin at the after end of an airship. When operated by the pilot it produces a yawing moment and gives directional control in the plane at right angles to the axis about which it is hinged or pivoted.

rudder angle—See ANGLE, RUDDER.

rudder bar—The foot bar by means of which the control cables leading to the rudder are operated.

rudder torque—The twisting moment exerted by the rudder on the fuselage. The product of the rudder area by the distance from its center of area to the axis of the fuselage may be used as a relative measure of rudder torque.

S

safety, factor of—See FACTOR OF SAFETY.
load in that member in actual use.

safety loop—See LOOP, SAFETY.

sag—A distortion of an airship in which the longitudinal axis becomes concave upward so that both ends rise.

sandbag line—See LINE, SANDBAG.

sea anchor—See ANCHOR, SEA.

seaplane—Any airplane designed to rise from and alight on the water. This general term applies to both boat and float types, though the boat type is usually designated as a "flying boat."

secondary shear wire—See WIRE (AIRSHIP), SECONDARY SHEAR.

semi-rigid airship—See AIRSHIP, SEMI-RIGID.

service tank—See TANK, SERVICE.

shaft, climbing—An access shaft fitted with a ladder and leading from the bottom to the top of an airship hull. This may be fitted in an airship of any type.

shaft, gas—A duct or shaft leading from the bottom of the gas cells to the outer cover of an airship. It affords a clear passage for the escape of gases which have accumulated in the gangway or corridor or which are discharged from the valves at the bottom of the cells. It usually consists of light wooden hoops or frames spaced at intervals on cords or wires and is covered by a netting. It prevents the gas cells from closing hard against one another and thus keeps the passage open. Sometimes called "gas trunk," "exhaust-gas shaft," or "trunk."

In view of the possibility of confusion with parts of an engine-exhaust system, it is believed that "gas shaft" or "trunk" is to be preferred.

sheathing—See TIPPING (PROPELLER).

shed—A shelter for housing airships.

ship—Slang for an airplane. In view of the confusion with "airship" it should not be used.

shipplane—A landplane designed to rise from and alight on the deck of a ship.

shock absorber—A device incorporated in the landing gear of an aircraft to reduce the shock imposed on the structure when alighting or taking off.

Shock absorbing devices are usually interposed between the main structure and the wheels, floats, skis, or tail skids, to secure resiliency in landing and taxying.

shore—A structural member for supporting the structure of a rigid or semi-rigid airship during building or docking, used in conjunction with (or without) a cradle.

side car—See CAR, WING.

side slipping—Flight in which the lateral axis is inclined and the airplane has a component of velocity in the direction of the lower end of the lateral axis. When it occurs in connection with a turn, it is the opposite of skidding. (q. v.)

sighting pendant—See PENDANT, SIGHTING.

skid—A runner used as a member of the landing gear and designed to aid the aircraft in landing or taxying.

tail skid—A skid used to support the tail when in contact with the ground.

wing skid—A skid placed near the wing tip and designed to protect the wing from contact with the ground.

skidding—Sliding sidewise away from the center of curvature when turning. It is usually caused by banking insufficiently, and is the opposite of side slipping. (q. v.)

skid fin—A fore-and-aft vertical surface, usually placed above the upper wing, designed to provide vertical keel surface and so to increase lateral stability.

skin friction—The tangential component of the fluid force at a point on a surface.

sky writing—The act of emitting from an aircraft a trail of smoke or other visible substance, the flight of the aircraft being so directed as to cause the trail to assume the form of letters or symbols.

sleeve, conical—A cone-shaped fabric, fitting in a bag or cell through which a line passes. It provides a gas-tight connection of the bag or cell to the line and yet permits both some degree of freedom to move.

sleeve, deflation—Generally a sleeve or appendix made of fabric provided for the special purpose of facilitating the deflation of an aerostat. Also applied to the sleeve or appendix fitted in the lower lobe of a kite balloon and used to permit the rapid escape of air in the lobes when the balloon is hauled down.

sleeve, filling—See SLEEVE, INFLATION.

sleeve, inflation (or sleeve, filling)—A tubular fabric attachment to an envelope or gas bag, serving as a lead for the inflation tube.

slip—The difference between the mean geometrical pitch and the effective pitch. Slip may be expressed as a percentage of the mean geometrical pitch or as a linear dimension.

slip fuel tank—See TANK, SLIP FUEL.

slip function—The ratio of speed of advance through the undisturbed air to the product of propeller diameter by the number of revolutions in unit time, i.e., $\frac{V}{ND}$. The slip function is the primary factor controlling propeller performance. It is π times the ratio of forward speed to the tip speed of the propeller.

slipstream—The stream of air driven astern by the propeller. (The indraft is sometimes included also.)

snatch-block anchorage—See ANCHORAGE, SNATCH-BLOCK.

soar—To perform sustained free flight without self-propulsion; it is called "up-current soaring" if performed in ascending air; "dynamic soaring" in other cases.

sounding balloon—See BALLOON, SOUNDING.

sound-ranging altimeter—See ALTIMETER, SOUND-RANGING.

span (airfoil)—The lateral dimension of an airfoil, i.e., its dimension perpendicular to its chord. Its symbol is b.

span (airplane)—The maximum distance measured parallel to the lateral axis from tip to tip of an airplane inclusive of ailerons.

spar—See WING SPAR.

specific fuel (or oil) consumption—See FUEL (OR OIL) CONSUMPTION, SPECIFIC.

speed, critical—The lowest speed of an aircraft at which control can be maintained.

speed, economic—The speed at which the fuel-consumption, per unit of distance covered in still air, is a minimum.

speed, ground—The horizontal component of the velocity of an aircraft relative to the earth.

speed, landing—The minimum speed at which an airplane can maintain itself in level flight and still be under adequate control.

speed, minimum—The lowest steady speed which can be maintained by an airplane in level flight at an altitude large in comparison with the dimensions of the wings, with any throttle setting whatever.

spin—A maneuver consisting of a combination of roll and yaw, with the longitudinal axis of the airplane inclined steeply downward. The airplane descends in a helix of large pitch and very small radius, the upper side of the airplane being on the inside of the helix, and the angle of attack on the inner wing being maintained at an extremely large value.

spindle, mooring—See OUTRIGGER, MOORING CONE.

spinner—A fairing of approximately conical or paraboloidal form, which is fitted coaxially with the propeller boss and revolves with the propeller.

spiral—A maneuver in which an airplane descends in a helix of small pitch and large radius, the angle of attack being within the normal range of flight angles.

spiral instability—See STABILITY.

stability—That property of a body which causes it, when disturbed from a condition of equilibrium or steady motion, to develop forces or moments which tend to restore the body to its original condition.

automatic—Stability dependent upon movable control surfaces automatically operated by mechanical means.

inherent—Stability of an aircraft due solely to the disposition and arrangement of its fixed parts, i.e., that property which causes it, when disturbed, to return to its normal attitude of flight without the use of controls or the interposition of any mechanical devices.

static—Stability of such a character that, if the airplane is displaced slightly from its normal attitude by rotation about an axis through its center of gravity (as may be done in wind tunnel experiments), moments come into play which tend to return the airplane toward its original attitude.

dynamic—Stability of such a character that, if the airplane is displaced from steady motion in flight, it tends to return to that steady state of motion, the oscillations due to restoring moments being damped out.

In a general way, the difference between static stability and dynamic stability is that the former depends on restoring moments alone, while the latter includes the action of damping factors.

longitudinal—Stability with reference to disturbances in the plane of symmetry, i.e., disturbances involving pitching and variation of the longitudinal and normal velocities.

directional—Stability with reference to rotations about the normal axis, i.e., and airplane possesses directional stability in its simplest form if a restoring moment comes into action when it is given a small angle of yaw. Owing to symmetry, directional stability is closely associated with lateral stability.

lateral—Stability with reference to disturbances involving rolling, yawing, or side slipping, i.e., disturbances in which the position of the plane of symmetry of the aircraft is affected.

spiral instability—A type of instability inherent in certain airplanes which becomes evident when the airplane, as a result of a yaw, assumes too great a bank and side slips; the bank continues to increase and the radius of the turn to decrease.

stabilizer—A normally fixed airfoil whose function is to lessen the pitching motion. It is usually located at the rear of an aircraft and is approximately parallel to the plane of the longitudinal and lateral axes. Also called "tail plane."

stabilizer (aerostat)— Same as FIN. The lobes of a kite balloon are sometimes referred to as stabilizers.

stabilizer, mechanical—A mechanical device to prevent an aircraft from departing from a condition of steady motion, or, in case such a motion is disturbed, to restore it to its steady state. Includes gyroscopic stabilizers, pendulum stabilizers, inertia stabilizers, etc.

stabilizer setting, angle of—See ANGLE OF STABILIZER SETTING.

stable oscillation—See OSCILLATION, STABLE.

stagger—The amount of advance of the leading edge of an upper wing of a biplane, triplane, or multiplane over that of a lower, expressed either as a percentage of gap or in degrees of the angle whose tangent is the percentage just referred to. It is considered positive when the upper wing is forward and is measured from the leading edge of the upper wing along its chord to the point of intersection of this chord with a line drawn perpendicular to the chord of the upper wing at the leading edge of the lower wing, all lines being drawn in a plane parallel to the plane of symmetry.

stall—The condition of an airplane when from any cause it has lost the air speed necessary for support or control.

static ceiling—See CEILING, STATIC.

static lift—See LIFT, STATIC (AEROSTAT).

static thrust—See THRUST, STATIC.

static trim—See TRIM, STATIC.

static turn indicator—See INDICATOR, STATIC TURN.

station, airship—The complete assembly of sheds, masts, gas plants, shops, landing fields, and related equipment required to operate airships and supply their needs. A station may include all or a part of the items enumerated. The base from which airships are operated.

statoscope—An instrument for detecting minute changes of altitude of an aircraft. The indications of the instrument usually depend on small changes of the static pressure of the air.

stay—A wire or other tension member; for example, the stays of the wing and body trussing.

step—A break in the form of the bottom of a float or hull designed to reduce resistance when under way by rapidly reducing the wetted surfaces as speed increases. It also serves to eliminate suction effects.

stern-droop—A deformation of an airship in which its longitudinal axis bends downward at the after end.

stern framing—See FRAMING, STERN.

stern-heavy—The condition in which, in normal flight, the after end of an airship tends to sink and which requires correction by means of the horizontal controls. In this condition an airship is said to "trim by the stern." It may be due to either aerodynamic or static conditions, or to both.

stiffener, bow—A rigid member attached to the bow of a non-rigid or semi-rigid envelope to reinforce it against the pressure caused by the motion of the airship. Sometimes called "nose stiffener" or "nose batten."

streamline—The path of a small portion of a fluid relative to a solid body with respect to which the fluid is moving. The term is commonly used only of such flows as are not eddying, but the distinction should be made clear by the context.

streamline flow—Steady flow past a solid body, i.e., a flow in which the direction at every point is independent of time.

streamline form—A solid body which produces approximately streamline flow.

stresses, breathing—Stresses produced in an aerostat by breathing. Of importance in the envelope and keel of a semi-rigid airship due to the interaction of envelope and keel when the envelope "breathes."

strip, drip—See FLAP, DRIP.

structural drag—See DRAG.

strut—A compression member of a truss frame. For instance, the vertical members of the wing truss of a biplane (interplane struts) and the short vertical and horizontal members separating the longerons (q. v.) in the fuselage.

strut, drag—A fore-and-aft compression member of the internal bracing system of a wing.

supercharged engine—See ENGINE, SUPERCHARGED.

supercharger—A mechanical device for supplying the engine with a greater weight of charge than would normally be induced at the prevailing atmospheric pressure and temperature.

centrifugal type—A supercharging device equipped with one or more rotating impellers generating centrifugal force which is utilized for the compression and the transmission of the air against resistance.

positive-driven type—A supercharger driven at a fixed speed ratio from the engine shaft by gears or other positive means.

rotary-blower type—A supercharging device comprising one or more relatively slow-speed rotors revolving in a stationary case in such a way as to provide a positive displacement.

turbo type—A supercharger driven by a turbine operated by the exhaust gases from the engine.

superheat—The amount by which the temperature of the gas in the envelope or gas cells of an aerostat is higher than the temperature of the surrounding air. If the contained gas has a lower temperature, the superheat is said to be negative.

superheat meter—See METER, SUPERHEAT.

supply balloon—See BALLOON, SUPPLY.

supply tube—See TUBE, SUPPLY.

supporting surface, main—See SURFACE, MAIN SUPPORTING.

surface, control—A movable airfoil designed to be rotated or otherwise moved by the pilot in order to change the attitude of the airplane or airship.

surface, fixed—See FIN.

surface, main supporting—A set of wings, extending on the same general level from tip to tip of an airplane; e.g., a triplane has three main supporting surfaces. The main supporting surfaces include the ailerons, but no other surfaces intended primarily for control or stabilizing purposes.

suspension band—See BAND, SUSPENSION.

suspension bar—See BAR, SUSPENSION.

suspension line—See LINE, SUSPENSION.

suspension, overhead—A line leading from the roof of an airship shed and arranged to sustain the whole or a part of the weight of the structure of an airship when it is docked.

suspension patch—See PATCH, SUSPENSION.

suspension winch—The rigging by means of which the lift and drag of a kite balloon is transmitted from the envelope to the towing or traction cable.

sweep back—The acute angle between the lateral axis of an airplane and the projection of the axis of the wing on the plane which includes the lateral and longitudinal axes. (The axis of a wing is a line through the centroids of the section of the wing.)

T

tail (airship)—Sometimes used for stern.

tail boom—A spar or outrigger connecting the tail surfaces and main supporting surfaces.

tail-droop—See STERN-DROOP.

tail group (or tail unit)—The stabilizing and control surfaces at the rear end of an aircraft, including stabilizer, fin, rudder, and elevator. (Also called "empennage.")

tail-heavy—In a heavier-than-air craft, the condition in which in normal flight, the tail sinks if the longitudinal control is released, i.e., the condition in which the pilot has to exert a push on the control stick to keep the given altitude.

tail-heavy (airship)—See STERN-HEAVY.

tail plane—See STABILIZER.

tail skid—See SKID.

tail slide—The backward and downward motion, tail first, which certain airplanes may be made to taken momentarily after having been brought into a stalling position by a steep climb.

tandem airplane—See AIRPLANE, TANDEM.

tank, fixed fuel—A fuel tank which is not intended or fitted to be dropped, as "slip" tanks are.

tank, service—A fixed fuel tank near each power unit, into which fuel from other tanks is pumped and from which the fuel supplying the engines is drawn.

tank, slip fuel—A fuel tank which is provided with a device permitting the quick dropping of the tank and contents as a whole in case of an emergency. Fitted on both airships and airplanes.

taxi—To run an airplane over the ground, or a seaplane on the surface of water under its own power.

testing, performance—The process of determining performance characteristics.

thermograph—An instrument for recording temperature.

thimble—A grooved ring of circular, pear-, or heart-shaped form, generally of metal, which is inserted in the eye of a rope or wire to prevent chafing or deformation of the eye.

three-point mooring—See MOORING, THREE-POINT.

thrust, effective—The net driving force delivered by a propeller when mounted on an airplane, i.e., the actual thrust given by the propeller, as mounted on an airplane, minus any increase of resistance of the airplane produced by the action of the propeller.

thrust face—See BLADE FACE.

thrust, static—The thrust developed by a propeller when rotating at a fixed point.

tipping (propeller)—A sheet-metal (or equivalent) protective covering of the blade of a propeller near the tip, extended a short distance along the trailing edge and a considerable distance along the leading edge.

toggle—A short crossbar of wood or metal which is fitted at the end of a rope. The rope passes around the mid length of the bar in a shouldered groove. By slipping it through an eye in the end of another rope, the two lengths of rope can be quickly connected or disconnected.

topping up—The operation of filling up with gas an already partially full aerostat. Also applied to a similar operation with fuel tanks. Incorrectly called "nursing."

total propeller-width ratio—See PROPELLER-WIDTH RATIO, TOTAL.

tower, mooring—See MAST, MOORING.

tractor airplane—See AIRPLANE, TRACTOR.

tractor propeller—See PROPELLER, TRACTOR.

trailing edge—The rearmost edge of an airfoil or propeller blade.

trail rope—See ROPE, DRAG.

trajectory band—See BAND, TRAJECTORY.

transverse, intermediate—An open unbraced transverse frame of a rigid airship which lies between two main or braced transverse frames.

transverse, main—A main transverse strengthening frame of a rigid airship provided with wire or girder bracing and spaced at regular intervals throughout the length of the airship.

trapeze bar—See BAR, SUSPENSION.

triangulation balloon—See BALLOON, TRIANGULATION.

trim—The attitude of an aerostat relative to a fore-and-aft horizontal plane. If the forward end is down, the aerostat is said to have "trim by the bow"; if the after end, it has "trim by the stern."

trim, to—To alter the attitude of an aerostat relative to a fore-and-aft horizontal plane. If the endeavor is to force the bow down, the aircraft is "trimmed by the bow"; if the stern, it is "trimmed by the stern." If the aircraft shows a tendency to sink by the bow end, it is said to "trim by the bow" or to be "bow-heavy"; if the tendency is to sink by the stern, it is said to "trim by the stern" or to be "stern-heavy."

trim, dynamic—Trim (or trimming) due to dynamic conditions or their change.

trim, static—Trim (or trimming) due to static conditions or their change.

triplane—An airplane with three main supporting surfaces, placed one above another.

trolley, docking—A car or trolley fitted on (or in) docking rails to transmit the pull of an airship docking line. It is fitted with wheels having anti-friction bearings so it can move freely in the rail. Usually some sort of quick-release device for letting go the line is also fitted.

tube, inflation—A fabric tube leading from the inflation manifold or source of supply to the inflation sleeve of the gas cell or envelope.

tube, nursing—See TUBE, SUPPLY.

tube, pressure—A tube fitted to an envelope or gas bag, to which a pressure gauge may be attached.

tube, supply—An elongated appendix or inflation sleeve, fitted on a kite balloon, which is brought down to the basket and fitted with a quick-connection coupling. This coupling can be attached to a similar piece on the deck of the airship and gas may be sent into the balloon shortly after it has reached the deck. A similar tube is sometimes used with airships where constant-pressure nurse balloons are used. This is rare in the United States. Also called "nursing tube."

turn indicator—See INDICATOR, TURN.

turn, reverse—A rapid maneuver to reverse the direction of flight of an airplane, made by a half loop and half roll.

U

unstable oscillation—See OSCILLATION, UNSTABLE.

useful lift—See LIFT, USEFUL (AIRSHIP).

useful load—See LOAD, USEFUL.

V

valve, automatic—A spring-loaded relief valve fitted to the envelope, ballonet, or gas cell of an aerostat and set to open at a predetermined pressure for the purpose of preventing excessive internal pressure.

Also applied to a type of valve used on some aerostats which opens at a predetermined contained volume or hull dimension.

valve cover—See HOOD, VALVE.

valve hood—See HOOD, VALVE.

valve, maneuvering—A manually operated valve fitted to the envelope, ballonet, or gas cell of an aerostat for the purpose of releasing gas or air from within the envelope or gas cell when desired.

valve petticoat—A special sleeve between valve and gas container making it possible to tie off the sleeve and change valves without loss of gas.

valve seal—A fabric cover used to seal the automatic valves of a rigid airship when docked in the shed. Jam pot cover (British).

veneer—Thin sheets of wood, either sliced with a knife or sawed.

vent, pressure-relief—A small opening in the covering of the fin of an airship intended to facilitate the equalization of the pressure of the air within the fin with that of the outside air. It also provides an outlet for any gas that may collect in the fin.

Venturi, power—A Venturi tube used to operate gyroscopic turn indicators and other instruments.

Venturi, speed-indicating—A Venturi tube may be combined with a Pitot tube or with a tube giving static pressure to form a pressure nozzle which may be used to determine the indicated speed of an aircraft through the air. The pressure difference is measured by a suitable gauge.

Venturi tube—A short tube with flaring ends and a narrow or constricted section between them, into which a side tube opens. When fluid flows through the Venturi, there is a reduction of pressure in the constricted section, the amount of reduction being a function of the velocity of flow.

vertical engine—See ENGINE, VERTICAL.

vertimeter—A device for indicating the rate of rise and fall of an aerostat, usually a special form of statoscope. A rate-of-climb meter serves the same purpose, although of a different form.

volume—The volume of the air displaced by the gas used for inflation.

volume, aerodynamic (airship)—The volume of the form which must be driven through the air. Same as "air volume."

volume, air (airship)—The volume of air displaced by the body formed by the outer cover or envelope of an airship. It is this volume which enters into aerodynamic computations. See VOLUME, AERODYNAMIC (AIRSHIP).

volume, gas (airship)—The volume of the contained gas. See CAPACITY.

V-type engine—See ENGINE, V-TYPE.

V-wires—The lower lines of the winch suspension of the kite balloon. They meet at the junction piece and form V's; hence the name.

W

walkway girder—See GIRDER, WALKWAY.

warp—To change the form of a wing by twisting it. Warping is sometimes used to maintain the lateral equilibrium of an airplane.

wash—The disturbance in the air produced by the passage of an airfoil. Also called the "wake" in the general case for any solid body.

washin—Permanent warping of the wing which results in an increase in the angle of attack near the tip.

washout—Permanent warping of a wing which results in a decrease in the angle of attack near the tip.

water-recovery apparatus—See APPARATUS, WATER-RECOVERY.

water-recovery condenser—See CONDENSER, WATER-RECOVERY.

weight, dischargeable (consumable weight) (airship)—All weight which can be consumed or discharged and still leave the airship in safe operating condition with a specified reserve of fuel, oil, water ballast, and provisions, and her normal crew.

weight, disposable (airship)—All weight other than fixed weights, including dischargeable weights contrasted with fixed weights, q. v.

weight, empty—The structure, power plant, and fixed equipment of an aircraft. Included in this fixed equipment are the water in the radiator and cooling system, all essential instruments and furnishings, fixed electric wiring for lighting, heating, etc. In the case of the aerostat the amount of ballast which must be carried to assist in making a safe landing must also be included.

weight, fixed (airship)—The weight of the hull machinery and all equipment and parts which are fixed in position and nonconsumable. All constant and nonconsumable weights which an airship would carry under all conditions of service (British). Liquids in cooling systems of engines are included.

weight, fixed power plant, for a given airplane—The weight of an engine, including ignition, carburetor, and induction systems complete, propeller and hub, exhaust manifolds, radiator and water, *if used,* with all interconnecting wires, controls, tanks, and pipes, lubricating oil temperature regulators, *the oil contained in the engine crankcase* and the starting gear attached to the engine, but excluding fuel, oil, and engine instruments.

weight per horsepower—The dry weight of an engine divided by the rated horsepower.

winch, suspension—See SUSPENION, WINCH.

windmill—An air-driven screw used to drive auxiliary apparatus on an aircraft.

window, inspection—A small transparent window fitted in the envelope of a balloon or airship, or in the wing of an airplane, to allow inspection of the interior.

wind, relative—The motion of the air with reference to a body, i.e., its motions as observed by a man at rest on the body. The direction and velocity of the relative wind, therefore, are found by adding two vectors, one being the velocity of the air with reference to the earth, the other being equal and opposite to the velocity of the body with reference to the earth.

wind tunnel—An elongated chamber, usually a tube divergent at the ends, through which a steady air stream may be drawn or forced. Models of airfoils, of aircraft, or of propellers may be placed in the middle portion of the tunnel, called the experiment chamber or working section, and supported by suitable balances placed out side the air stream, so that the forces, moments, etc., due to the moving air may be measured.

wing—A general term applied to a whole or a portion of the main supporting surfaces of an airplane, but in the latter case is usually qualified as right wing, left wing, upper wing, or lower wing, etc.

wing car—See CAR, WING.

wing-dihedral angle—See ANGLE, WING-DIHEDRAL OR DIHEDRAL.

wing drag—See DRAG.

wing-heavy—The condition of an airplane in which (in normal flight) there is a tendency for the right (or left) wing to drop, if the lateral control

is released, i.e., the condition in which the pilot has to exert a lateral force on the control stick to keep the lateral axis horizontal.

wing loading—See LOADING, WING.

wing rib—A fore-and-aft member of the wing structure of an airplane, used to give the wing section its form and to transmit the load from the fabric to the spars.

rib compression—A heavy rib designed to have the function of a wing rib and also to act as a strut opposing the pull of the wires in the internal drag-truss. (Also called "Drag strut.")

rib, former or false—An incomplete rib, frequently consisting only of a strip of wood extending from the leading edge to the front spar, which is used to assist in maintaining the form of the wing where the curvature of the airfoil section is sharpest.

wing setting, angle of—See ANGLE OF WING SETTING.

wing skid—See SKID.

wing spar—The principal transverse structural member of the wing assembly of an airplane.

wing truss—The framing by which the wing loads of an airplane are transmitted to the fuselage. It comprises struts, wires, cables, tie rods, and spars.

wire—In aeronautics, refers specifically to drawn solid wire.

wire (airship):

antiflutter—A wire in the plane of the outer cover for locally reinforcing the outer cover in that part of the airship and reducing fluttering in flight due to air pressure or propeller wash. Also called "outer cover support wire."

chord—A wire joining the vertices of the polygonal frame of the main transverse frame.

diametral—A chord wire which passes through or near the center of the main transverse frame. It is usually attached to the axial fitting.

fairing—A wire provided as a point of attachment for the outer cover to maintain the contour lines of the envelope of an airship.

main shear—A diagonal wire taking up mean shear loads in the structure of a rigid airship.

netting—Diagonal and/or circumferential wire netting fitted between the longitudinals over the entire hull of a rigid airship, to transmit the lift of the gas cells to the structure. Sometimes called "gas pressure wires."

radial—A wire which extends from an axial fitting at the center of the transverse frame of a rigid airship to a joint of the frame.

secondary shear—Additional reinforcing shear wire.

wire, antidrag—A wire designed primarily to resist forces acting parallel to the chord of the wing of an airplane and in the same direction as the direction of flight. It is generally inclosed in the wing.

wire drag—Any wire or cable designed primarily to resist drag forces.

internal—A drag wire concealed inside the wing.

external—A drag wire run from a wing to the fuselage or other part of the airplane.

wire, landing—A wire designed primarily to resist forces in the opposite direction to the normal direction of the lift and to oppose the lift wire and prevent distortion of the structure by an overtightening of those members. Sometimse called "antilift" wire.

wire, lift—A wire or cable which transmits the lift on the outer portion of the wing of an airplane in toward the fuselage or nacelle. This wire usually runs from the top of an interplane strut to the bottom of the strut next nearer the fuselage. Sometimes called "flying wire."

wire, stagger—A wire connecting the upper and lower surfaces of an airplane and lying in a plane substantially parallel to the plane of symmetry. (Also called "incidence wire.")

wood, laminated—A product formed by gluing or otherwise fastening together a number of laminations of wood with the grain substantially parallel. (Differs from plywood in that in the latter the grain of alternate plies is usually crossed at right angles; also, the plies of the latter are usually made up of veneer.)

W-type engine—See ENGINE, W-TYPE.

Y

yaw, angle of—See ANGLE OF YAW.

yaw guy—See LINE, YAW.

yaw line—See LINE, YAW.

yawmeter—An instrument for measuring the angle of yaw.

Z

zero-lift angle—See ANGLE, ZERO-LIFT.

zero-lift line—A line through the trailing edge of an airfoil section parallel to the direction of the wind when the lift is zero.

zoom—To climb for a short time at an angle greater than that which can be maintained in steady flight, the airplane being carried upward at the expense of its kinetic energy. This term is sometimes used as a noun, to denote any sudden increase in the upward slope of the flight path.

AERONAUTICAL SYMBOLS

1. Fundamental and Derived Units

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	sec	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/sec		horsepower	HP.
Speed		km/hr		mi./hr.	M. P. H.
		m/sec		ft./sec	f. p. s.

2. General Symbols, Etc.

W, Weight, $= mg$

g, Standard acceleration of gravity$=9.80665$ m/sec.^{2}$=32.1740$ ft./sec.^{2}

m, Mass, $= \dfrac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} sec.^{2}) at 15° C and 760 mm = 0.002378 (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m^3 = 0.07651 lb./ft.^{3}

mk^2, Moment of inertia (indicate axis of the radius of gyration, k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord length.

b/c, Aspect ratio.

f, Distance from c. g. to elevator hinge.

μ, Coefficient of viscosity.

3. Aerodynamical Symbols

V, True air speed.

q, Dynamic (or impact) pressure $= \frac{1}{2} \rho V^2$

L, Lift, absolute coefficient $C_L = \dfrac{L}{qS}$

D, Drag, absolute coefficient $C_D = \dfrac{D}{qS}$

Ç, Cross-wind force, absolute coefficient $C_C = \dfrac{C}{qS}$

R, Resultant force. (Note that these coefficients are twice as large as the old coefficients L_C, D_C.)

Angle of setting of wings (relative to thrust line).

Angle of stabilizer setting with reference to thrust line.

Dihedral angle.

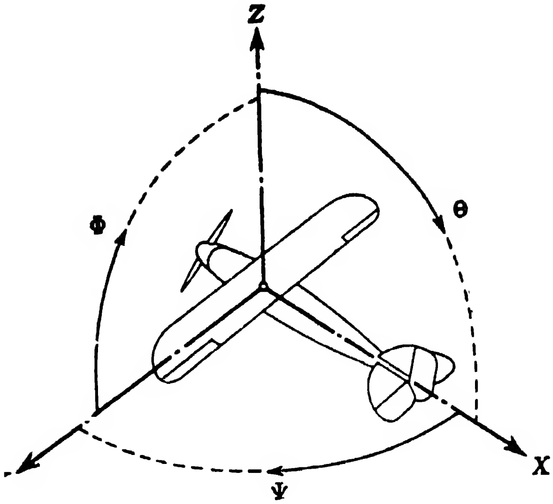
$\rho \dfrac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, 0° C:255,000 and at 15° C., 230,000;

or for a model of 10 cm chord 40 m/sec, corresponding numbers are 299,000 and 270,000.

C_p, Center of pressure coefficient (ratio of distance of C. P. from leading edge to chord length).

β, Angle of stabilizer setting with reference to lower wing, $= (i_t - i_w)$.



Positive directions of axes and angles (forces and moments) are shown by arrows

Axis			Moment about axis			Angle		Velocities	
Designation	S	alle mb	g	Sym	Posi direc	Designa ion		ar compo along axis	gu
Longitudinal ..	X	X	rolling..	L	Y—Z	roll ...	Φ	u	
Lateral	Y	Y	pitching	M	Z—X	pitch...	θ	v	
Normal	Z	Z	yawing..	N	X—Y	yaw...	Ψ	w	

α, Angle of attack.

ϵ, Angle of downwash.

Absolute coefficients of moment $C_L = \frac{L}{qbS}$ $C_M = \frac{M}{qcS}$ $C_N = \frac{N}{qfS}$

Angle of set of control surface (relative to neutral position), . (Indicate surface by proper subscript.)

4. Propeller Symbols

D, Diameter.
p_e, Effective pitch.
p_g, Mean geometric pitch.
p_s, Standard pitch.
p_v, Zero thrust.
p_a, Zero torque.
p/D, Pitch ratio.

V', Inflow velocity.
V_s, Slipstream velocity.
T, Thrust.
Q, Torque.
P, Power.

(If "coefficients" are introduced all units used must be consistent.)

η, Efficiency $= T\,V/P$.
n, Revolutions per sec., r. p. s.
N, Revolutions per minute., R. P. M.
Φ Effective helix angle $= \tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. Numerical Relations

1 HP. = 76.04 kg/m/sec. = 550 lb./ft./sec.
1 kg/m/sec. = 0.01315 HP.
1 mi./hr. = 0.44704 m/sec.
1 m/sec. = 2.23693 mi./hr.
1 lb. = 0.4535924277 kg.
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.

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